ENGINEERING CASE LIBRARY

ECL 92A

Design and Fabrication of a Seawater Test Chamber at Chicago Bridge and Iron Company (A)

Underwater exploration of the sea is the next major challenge to be met by man. Many Federal Government Agencies are interested in this subject, and funds have been appropriated to launch several large scale test programs.

Early in 1965, the Arctic Sciences and Technology Division of the United States Navy Electronics Laboratory at San Diego, California, asked CB&I* to bid on the design and fabrication of a seawater experimental test chamber. The vertically standing test chamber was to be used by the Laboratory to conduct experiments simulating deep arctic sea conditions. The vessel was to be of cylindrical construction with an inside diameter of 50 to 60 inches and a working length of 120 inches. It was to have a hemispherical fixed end closure and a removable, fast acting top end closure. The internal working pressure range was specified as 5,000 to 10,000 psig, while the working temperature range was given as 28°F to 80°F.

*CB&I is the abbreviation for Chicago Bridge and Iron Company.

This case was prepared by Professors Karl H. Otte and Otto E. Widera of the University of Illinois, at Chicago Circle during the 1967 Summer Institute on Case Methods. The Institute was supported by the National Science Foundation and held at the University of Illinois in Chicago. The cooperation of Messrs. Rober Reedy, Lester Pheiffer and Ewald Schmitz of CB&I is gratefully acknowledged.

Chicago Bridge and Iron Company

CB&I's history goes back to its founding in 1889, initially as a bridge building firm in Chicago. Some five years later, the Company branched into the steel plate field -- designing, fabricating and constructing round and elevated steel tanks for water storage. Bridge building was discontinued prior to World War I as opportunities grew in steel plate work. With the discovery of great oil fields in the 1920's, CB&I quickly established itself as a leading supplier to the industry. It designs and builds every conceivable type of storage tank and processing structure. A continuous program of research and development subsequently led CB&I into many other fields. The company, for example, has designed, engineered, fabricated and constructed complete space simulation systems, nuclear containment vessels, cryogenic storage vessels and evaporator systems for the pulp and paper industry. CB&I and its domestic and foreign subsidiaries had sales for 1966 exceeding 300 million dollars.

The research and development work of the Company is directed from Oak Brook, Illinois. Separate groups are devoted to chemical processes, vacuum technology, cryogenics, electronics and other studies at Company laboratory and pilot plant facilities in Plainfield, Illinois. A welding and metallurgical laboratory is located in Oak Brook. Also headquartered at Oak Brook is the Development and Technical Consulting group. This group is responsible for developing new products, finding new uses for current products and improving existing designs. Regional engineering staffs handle work associated with individual contracts at all major plants.

The major manufacturing facilities of the Company are located at Chicago, Birmingham, Salt Lake City, Houston and Greenville, Pennsylvania. In addition to heavy presses, planers, plate rolls and other shop equipment, most of these plants have stress-relieving furnances, radiographic machines, and facilities for the acid pickling of steel to remove mill scale.

Much of the equipment was specially designed by Company engineers and was fabricated in Company shops to do a specific job. Each of the major plants also has a staff of engineers as well as welding and metallurgical research facilities.

Field construction is the final phase of CB&I's service. The Company often has as many as 200 construction crews active at one time building a variety of structures anywhere in the world. All are equipped with the tools necessary to perform such functions as materials handling, welding, x-raying, stress relieving and testing. Technical assistance and designs for special equipment are provided to all field crews by the General Construction engineering staff at Oak Brook.

MULTILAYER Vessels

In February of 1963, CB&I acquired exclusive rights from A. O. Smith Corporation of Milwaukee, Wisconsin, to manufacture and sell MULTILAYER Vessels in the United States and Canada. These rights include technical assistance from A. O. Smith experts as well as patents and machinery relating to the production of MULTILAYER Vessel.

The MULTILAYER Vessel derives its name from the multiplicity of layers of steel, which make up the wall. Exhibit A-1 shows the principal construction features. The inner shell is the innermost band of the vessel and is fabricated in the same manner as any solid wall vessel. If corrosion protection is required, the inner shell may be fabricated of solid nonferrous plate or conventional clad plate with alloy on carbon steel or low alloy backing. The seams are radiographed and, with internal roundout rings installed, stress relieved prior to the wrapping of subsequent layers. The thickness of the inner shell is normally a function of vessel diameter and varies from 3/8" to 1" in thickness. Each layer is progressively wrapped around the inner shell by mechanical means, and the longitudinal seam butt welded. Layers are normally 1/4" or 9/32" thick.

All layer longitudinal welds are staggered relative to each other and ground flush prior to application of the subsequent layers. The ends of the MULTILAYER shell sections are machined scarfed for welding to adjoining shell sections and closures.

As Exhibit A-1 illustrates, the inner shell is pressure tight. The load bearing layers are vented to the outside. If a leak should develop in the inner shell, through exposure to corrosive elements or other operating conditions beyond the design capability, the process fluid or gas would be vented through the layer vents for immediate detection and corrective action before a serious failure could occur.

The combination of the wrapping load imposed during fabrication of the MULTILAYER shell by the wrapping machine and the weld shrinkage of the longitudinal layer seams provides desirable stress distribution for working pressures anticipated in the operation of the vessel. The MULTILAYER construction provides flexibility and welding requirements are only those of thin wall shells. In welding the girth seams, the layers immediately above the top of the weld as it is being built up do not conform to the shrinkage of the weld layer immediately below. This has the effect of having the weld shrinkage longitudinally affect only one layer at a time except at the longitudinal seam where a maximum of two layers are affected. The resultant shrinkage stress is only a fraction of that developed in solid wall vessels. Weld shrinkage in the circumferential direction is controlled by peening and induces desirable compressive stresses in the weld metal similar to those which are inherent in the MULTILAYER shell construction. Stress relieving of the MULTILAYER vessels, therefore, is not required. Also, it is desirable to retain the built-in compressive stresses for better stress distribution.

The thin plate metallurgy provides uniform properties across the full shell regardless of thickness, and compares with the possible variable properties of heavy heat treated shell plates. Also, the use of multiple layers not only resists initiation of failures but also serves to prevent propagation into adjacent layers. Should fracture

occur in any layer, the load is shifted to the other layers without compounding or magnifying the force. Initiation would occur in other layers only if the pressure force is sufficient to burst the full thickness. Since the operating pressure is well below the bursting pressure, the possibility of catastrophic failure is almost inconceivable. Tests, including forced local failures deliberately started by impact, have confirmed that MULTILAYER Vessel construction will not shatter and that failure propagates only within individual layers.

United States Navy Specifications

The United States Navy Research Departments are interested in testing components for submarines for deep water service. Ninety-seven percent (97%) of the oceans depths and area can be simulated by hydraulic testing for collapse pressures in the range of 10,000 psi. The deepest parts of the ocean, covering only 3% of the area, would require double this pressure.

Early in 1965, the Arctic Sciences and Technology Division of the United States Navy Electronics Laboratory at San Diego, California, asked CB&I to bid on the design and fabrication of a MULTILAYER Vessel to be used in conducting experiments simulating deep arctic sea conditions. Exhibit A-2 shows some of the relevant bidding specifications for this vessel. The desired mechanical features of the vessel are shown in Exhibit A-3.

Design Procedures

The American Society of Mechanical Engineers (ASME) has written many rules for construction codes for both boilers and unfired pressure vessels.

In 1911 the ASME set up a committee for the purpose of formulating standard rules for the construction of steam boilers and other pressure vessels. This committee is now called the Boiler and Pressure Committee. Its function is to establish rules of safety governing the design, the

fabrication and the inspection during construction of boilers and unfired pressure vessels, and to interpret these rules when questions arise regarding their intent. In formulating these rules, the Committee considers the needs of users, manufacturers and inspectors of pressure vessels.

Industry, engineering firms, suppliers and insurance companies are represented on the many code subcommittees, and final action is by the main committee.

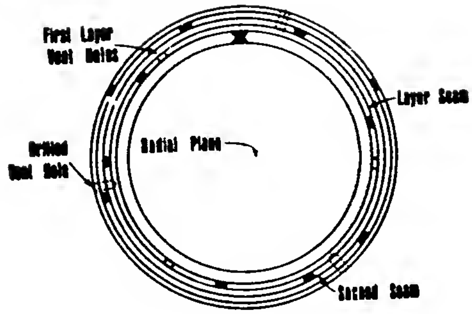
The safety of the public is the prime factor for determining the rules of construction and many states and municipalities in the United States have adopted or accepted sections of the Boiler and Pressure Vessel Code. This consideration usually determines the design stress basis. The seawater test chamber is to be designed for a stress of the minimum ultimate strength of the material divided by four. Exhibit A-4 gives some information on the design formulas specified in Section VIII of the ASME Code.

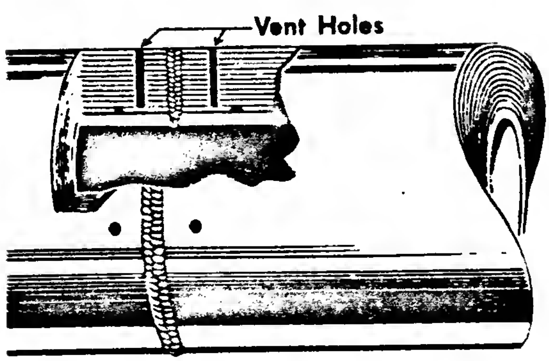
Although the type of shell construction specified in the Navy request for a bid is MULTILAYER, there are a number of ways to fabricate cylindrical shells for pressure vessels. Prior to the days of welding, this meant a large forging. The size of forgings though, is limited by the size of the ingot and the supplier's forging equipment. It is common today to use solid wall construction for vessels having a diameter of six feet and over since presses needed to form the needed thick walled plates are now available.

<u>Assignment for Student:</u>

1. Prepare a preliminary design (including sketch) for the seawater test chamber.

2. Compare MULTILAYER pressure vessel design with that using solid wall construction.


First Layer
Layer Seam


Vent Holes

SPECIFICATIONS FOR A CYLINDRICAL EXPERIMENTAL

SEAWATER TEST VESSEL

1.0 GENERAL:

This specification describes the critical mandatory research and development features required for one Seawater Experimental Vessel, 50 to 60 inch diameter, cylindrical, multilayer construction with hemispherical fixed end closure and a removable top end closure, monel lined, 10,000 psi operating pressure for use at the Arctic Sciences and Technology Division of the U. S. Navy Electronics Laboratory, San Diego, California 92152.

1.1 A laboratory, high internal pressurized vessel is required for conduct of experiments simulating deep arctic sea conditions. The vessel in itself is highly R&D experimental and is a single, "one of kind" equipment specifically designed and fabricated for intended laboratory use in conjunction with the arctic experimental pool at the U. S. Navy Electronics Laboratory.

1.2 The vessel shall have a multi-layer cylindrical shell section built of concentric layers of steel plate wrapped under tension and welded together. Bottom end closure shall be a fixed hemispherical closure. The top end closure shall be removable giving full access to the sylindrical test section. The vessel shall have a monel liner.

1.3 The inside diameter shall be between 50 and 60 inches depending on cost and form of removable end closure. Each bid proposal must include the price of a vessel fo 50 inche inside diameter and the price of a vessel of 60 inch inside diameter. Final inside diameter will be determined at time of contract award.

1.4 Because of the experimental character of the vessel, the form of removable end closure and fittings are not detailed. Therefore, each bid proposal must include a description of the following items which the bidder will use:

(a) Removable top end closure.
(b) Access Port.
(c) Bottom drain/fill connection.
(d) Specifications of materials of construction.

1.5 Each proposal should give estimated delivery time from date of contract award.

1.6 Each proposal should quote F. O. B. factory delivery. It is planned to ship vessel by Government Bill of Lading after inspection and acceptance at the factory by NEL Technical Advisor and Inspector of Naval Material.

2.0 DIMENSIONS:

The vessel shall be sylindrical type with a top removable end closure. The sylindrical working section shall be between 50 and 60 inches inside diameter and 120 inches in length from inside face of top removable closure to center of inside face of fixed hemispherical lower end closure. Final inside diameter will be specified in contract award.

3.0 OPERATING CONDITIONS:

The vessel shall be designed for an internal working pressure range of 5 to 10,000 psig and a working temperature range of 28°F. to 80°F. The working fluid is seawater of variable salinity, maximum 35 parts per thousand.

3.1 The vessel shall operate in a vertical position, and the upper closure of the vessel shall be designed accordingly to permit clear access to the full inside diameter of the cylindrical test cross-section.

3.2 The upper closure shall be an interrupted threaded type or clamp-ring type to facilitate removal and reinstallation. The weight of any component of the removable closure shall not exceed 15,000 lbs. (maximum working load of bridge crane operating over vessel.)

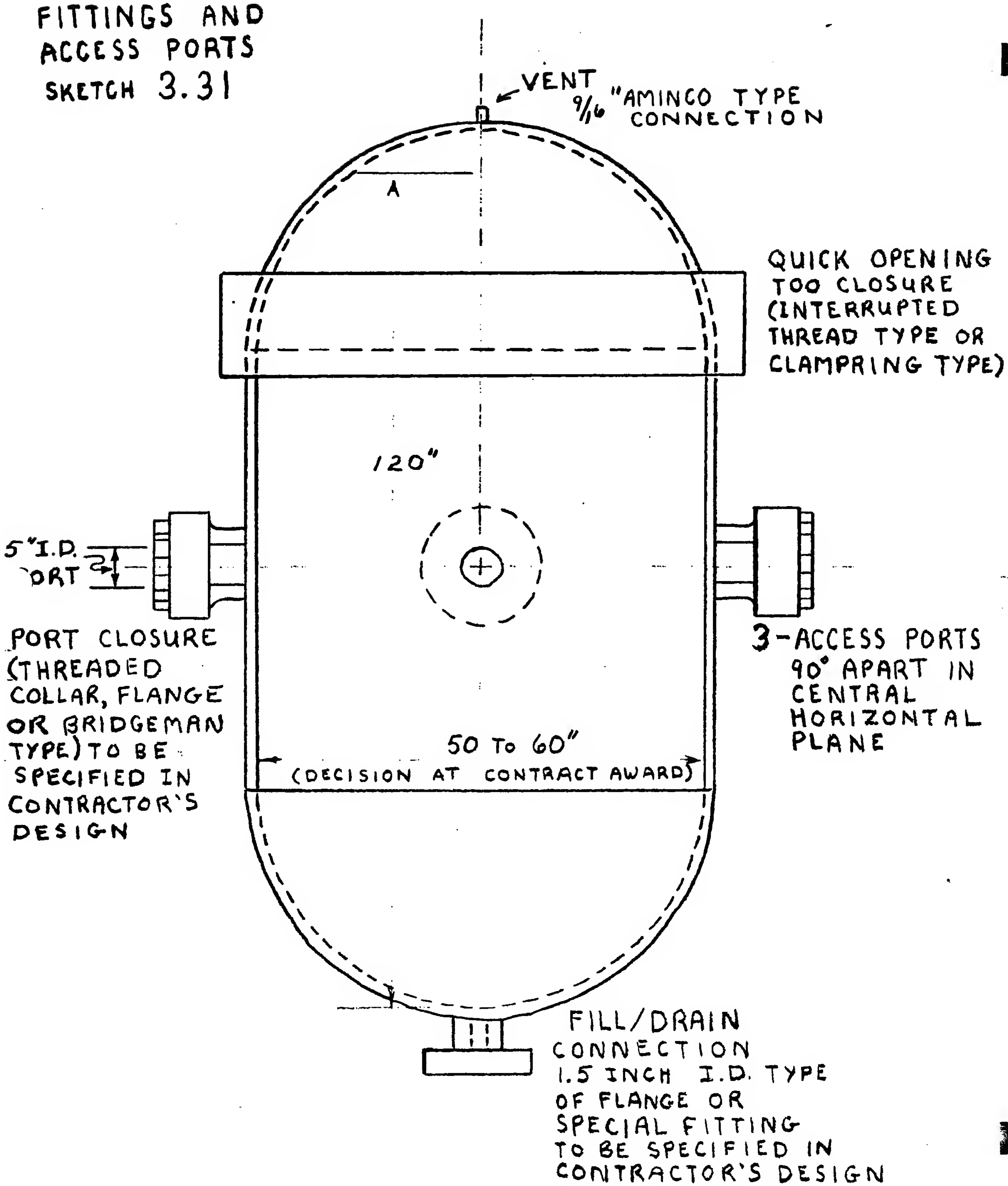
3.3 Fittings to the vessel shall consist of three access ports, 5 inch inside diameter, a 9/16 inch top vent, and a 1.5 inch inside diameter drain/fill bottom connection, as indicated in attached sketch 3.31. The three access ports are located in the central horizontal plane of the cylindrical test section with 90° separation.

3.4 The contractor shall provide design details of access ports and connections in the set of working drawings submitted for certification under Paragraph 8.0. The contractor shall recommend the form of the foundation to be used for the permanent installation of the vessel. (Note: the foundation to be used for the permanent installation of the vessel is not a part of this contract).

4.0 DESIGN AND FABRICATION:

The vessel will be of multiple layer construction and shall be designed, fabricated and tested in accordance with the applicable provisions of the ASME Boiler and Pressure Vessel Code and shall be stamped "California Special".

FITTINGS AND ACCESS PORTS SKETCH 3.31



MULTILAYER VESSEL DESIGN PROVEN

Several design formulas and corresponding allowable stress values are used throughout industry for designing vessels for extremely high pressures—beyond the standardizing influence of the ASME Code.

The appropriate basis for designing MULTILAYER Vessels was developed and proven through extensive tests. The many full scale vessels built and tested to destruction, in the most comprehensive and thorough research program of its kind, have confirmed the design formulas without exception.

The design information derived from these tests and the knowledge and experience gained in designing, building and testing MULTILAYER Vessels is incorporated in each vessel to meet individual process and storage requirements. The safe design limits established through test and experience are never exceeded.

Section VIII of the ASME Code specifies the use of the Lamé Formula for determining the thickness of a vessel when the R/t, ratio is less than 2

$$t = R\left[\sqrt{\frac{SE + P}{SE - P}} - 1\right]$$

where
t = wall thickness, inches
R = inside radius, inches
S = allowable unit stress on inside surface, pounds per square inch
E = joint efficiency
P = design pressure, pounds per square inch

For R/t's greater than 2, the Code formula is

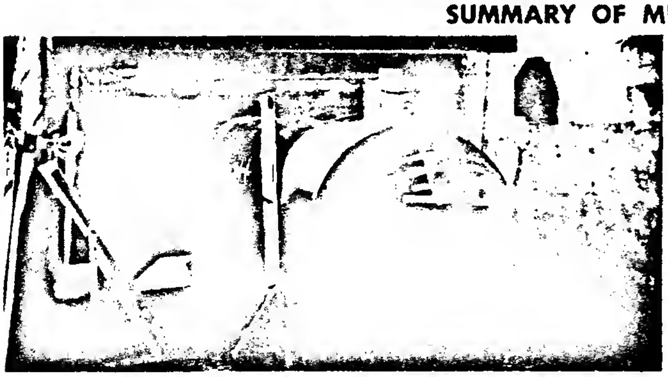
$$t = \frac{PR}{SE - 0.6P}$$

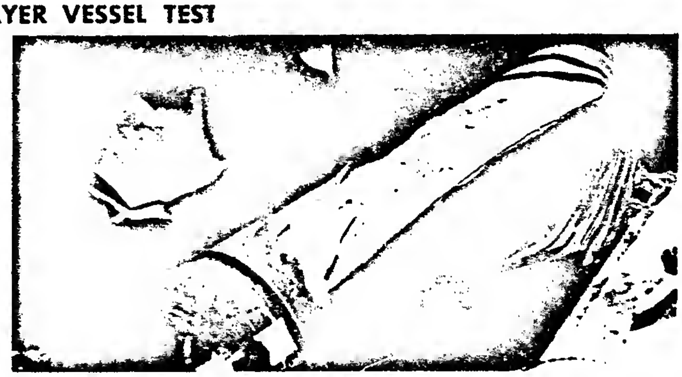
This formula approximates the Lamé Formula for the higher design pressures where MULTILAYER Vessels are particularly applicable. Consequently, the Lamé Formula is used over a somewhat wider range of pressures than specified by the Code. A joint efficiency of 100 per cent is normally used in the design because the longitudinal welds in the individual layers of a MULTILAYER Vessel do not line up in any radial plane. The joints in the inner shell are fully radiographed and the inner shell sections are postweld heat treated.

Both the maximum stress on the inner surface, as determined by the Lamé Formula, and the average stress at the burst pressure are of interest when selecting an allowable stress level.

Many of the more than 10,000 MULTILAYER Vessels built have been designed using allowable stresses comparable to those given in Section VIII of the ASME Code—1/4 of the ultimate strength of the material. Approximately 25 per cent of the vessels were designed by limiting the calculated stress at the inner surface, as determined by the Lamé Formula, to 1/2 the yield strength of the material. The safety record of the MULTILAYER Vessel, coupled with industry's need for economical vessels at higher and higher pressures, often dictates the use of a lower factor of safety against

SUMMARY OF MULTILAYER VESSEL TEST



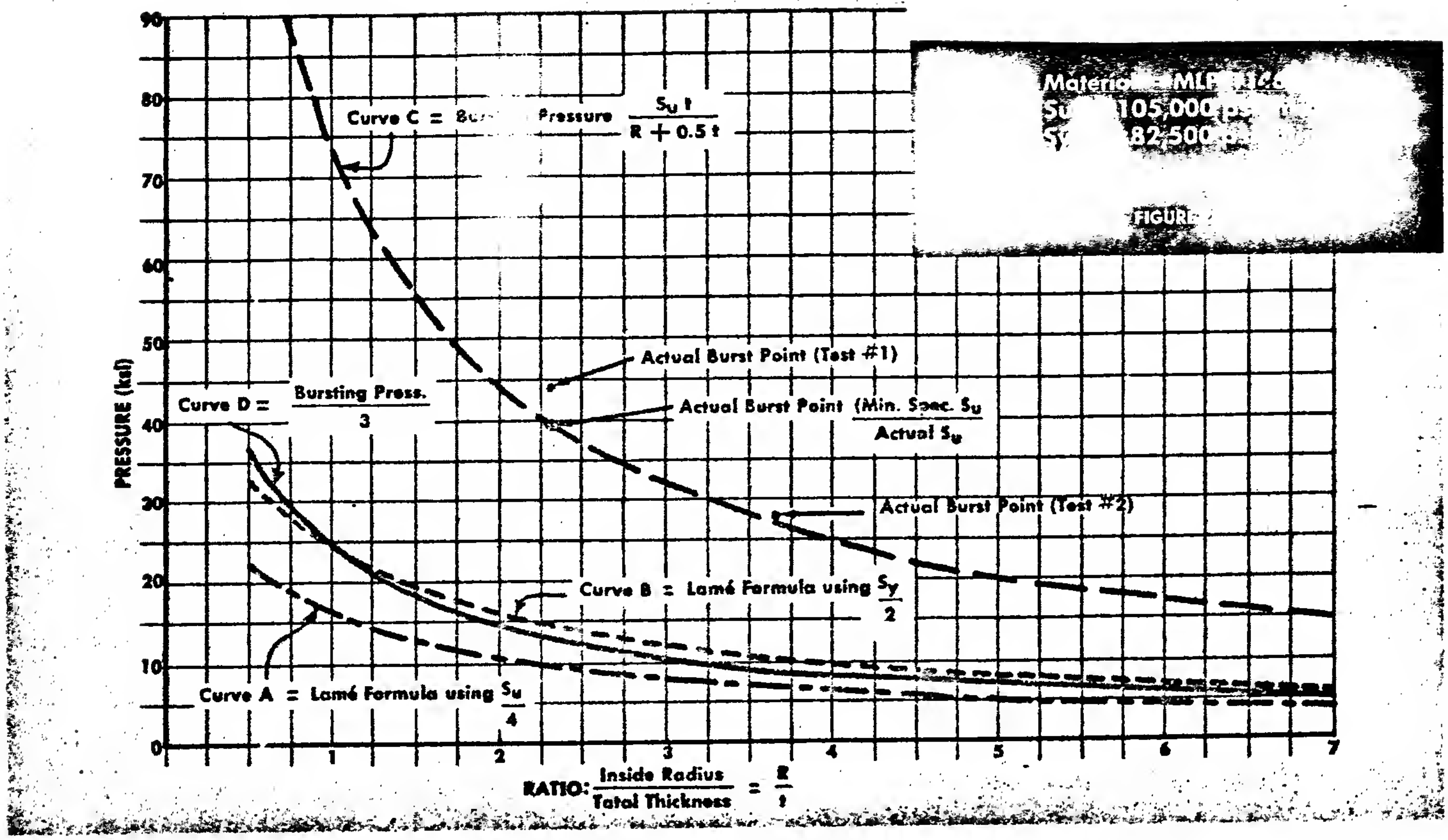


The above photographs show a full scale MULTILAYER Vessel 4⅜ inches thick before and after testing to destruction. Test vessel was of the 1146B material and evidence of local failure first appeared at the superpressure of 44,150 pounds per square inch, utilizing 100 per cent of the material strength. After an additional ten minutes of pumping to force complete failure the burst started at the outer layers. The vessel remained in one piece without fragmentation while releasing 15 million foot pounds of stored energy.

		Pressure psi developed during burst test	Stress Intensity In Vessel Calculated by $S = \frac{PR}{t} + \frac{P}{2}$	Stress in Vessel Calculated by Lamé Formula $S = P\left[\frac{(1+\frac{t}{R})^2+1}{(1+\frac{t}{R})^2-1}\right]$	Strength of Layers psi
Test #1	Vessel R/t ratio = 2.28 to 1				
Test #2	= 3.68 to 1				
Test #1	At yield strength*	38,250	106,300	110,000	93,500 Average
	At ultimate strength	44,150	122,700	128,000	122,000 Average
Test #2	At yield strength*	24,250	101,475	103,000	82,500 Min. specified
	At ultimate strength	27,900	116,650	118,000	110,000 Min. specified

*Measured by volumetric change.

TABLE 2



...st, particularly for the simple cylindrical shell. A large number have been built with a safety factor of 3 based on the burst pressure.

Figure 2 illustrates the limitations and ranges of the Lamé Formula for inner surface stresses equal to 1/4 the ultimate strength (Curve A) and 1/2 the yield strength (Curve B) of the 1146B material — 110,000 minimum tensile strength. Curve D is based upon 1/3 the bursting strength. Curve C, the vessel bursting pressure, is based upon the average stress intensity though the wall, $S = \frac{PR}{t} + \frac{P}{2}$, since this correlates more closely with actual bursting pressures than does the Lamé Formula. The results of a burst test of a vessel fabricated of the 1146B material is summarized in Table 2 and plotted in Figure 2 to illustrate the validity of the calculated burst strength curve.

MULTILAYER Vessel construction utilizes a patented, prestressing system that assures full and effective participation of the entire vessel wall and permits the designer to extend the range in which the inner shell will be stressed elastically both during operation and test conditions. This prestress reduces the magnitude of the tensile stress at the inside surface for *all* R/t ratios. When the working pressure becomes extremely high (small R/t ratios) the reduction in stress provides the desired factor of safety without excessive wall thicknesses.

Circumferential stress-strain readings taken on the interior surfaces of MULTILAYER Vessel cylinders show a progressively increasing compression in the inner shell during the wrapping and welding operations. The stress reduction realized through prestress is shown graphically in Figure 3 for a thick walled cylinder ($R/t = 1$) under pressure. The graphical representation of the problem encountered with extremely high pressures shows the balancing effect of initial compression on the inside and tension on the outside produced in MULTILAYER Vessels.

The stress distribution due to pressure without prestress is shown by the curve ABC. The maximum stress occurs at point A and is equal to $\frac{5}{3}$p or 100 percent. Curve DEF represents the ideal prestress such that when it is combined with Curve ABC results in the uniform stress of Curve GBH, equal to only 60 per cent of the maximum at point A or equal to P in this example. The precompression represented by the area IED equals the tension represented by the area EJF.

When the working pressure equals or approaches the allowable stress, the Lamé Thickness Formula alone is no longer applicable for it then yields an infinitely thick wall.

In this general range of pressures, a design approach that recognizes the initial precompression and the resulting safe average stress intensity becomes necessary.

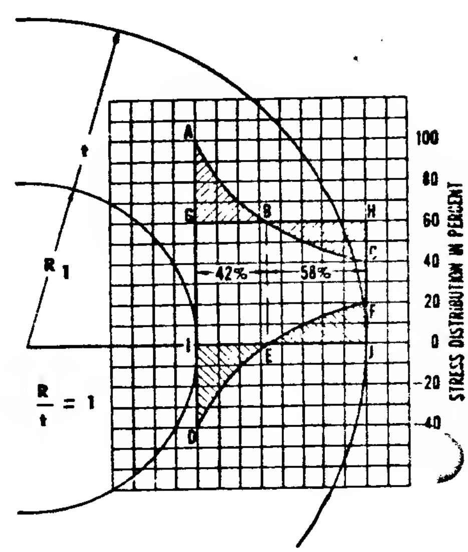


FIGURE 3

ENGINEERING CASE LIBRARY

ECL 92B

Design of a Seawater Test Chamber

at

Chicago Bridge and Iron Company (B)

The design phase of this project was the responsibility of the special Structures Engineering Department with Lester Pfeiffer assigned as project engineer. He is a mechanical engineering graduate of Marquette University and has more than twenty years of experience with both A. O. Smith Corporation and CB&I. Associated with him on this project was Ewald Schmitz, a product engineer and machine designer who also came to CB&I when they obtained the rights and patents for MULTILAYER construction from A. O. Smith. Ewald is a graduate of the Koethen Polytechnic Institute in Germany and has thirty-seven years of experience in pressure vessel design.

The design and fabrication of shop-built CB&I MULTILAYER pressure vessels is governed by CB&I Standard 4400-1 (MLS-30) and is given in Exhibit B-1. Material specification standards 626-5002 and 626-1146 used for high strength low alloy steel are listed as Exhibits B-2 and B-3 respectively. These materials are proprietary and specially developed for MULTILAYER construction by a joint venture between CB&I and the steel supplier. The allowable stresses are usually based on 1/4 the ultimate strength of the materials.

This case was prepared by Professors Karl H. Otte and Otto E. Widera of the University of Illinois at Chicago Circle during the 1967 Summer Institute on Case Methods. The Instutute was supported by the National Science Foundation and held at the University of Illinois in Chicago. The cooperation of Messrs. Roger Reedy, Lester Pfeiffer and Ewald Schmitz of CB&I is gratefully acknowledged.

Guided by the Navy bid specifications and the CB&I specifications, Pfeiffer and Schmitz designed the test chamber shown in Exhibit B-6. Inspection of this drawing discloses the following noteworthy features:

1. The inner shell which is in direct contact with seawater is 1/2" thick shell of SA225Gr B FB steel including a 1/8" thick cladding of monel to resist corrosion.
2. The bottom end is a one piece forging having the inner surface coated with a 1/8" layer of monel for resistance to corrosion. The forging is made of #5002B steel strong enough to contain the specified pressure and at a lower cost than making multiple drawing dies for precisely fitting into a MULTILAYER head.
3. The nozzle and other connections are #5002B steel lined with 1/8" monel sleeves and welded into the MULTILAYER shell from the inside. The shell is made thick enough to reinforce the opening so the nozzle need only resist the internal pressure in the nozzle. Their strength is adequate and no special forming tools are needed.
4. The top cover is #5002B steel forging coated on the inside with a 1/8" layer of monel. It is supported on a shoulder ring and sealed against leakage with double monel gaskets as shown in the detail on the print. It is moved into and out of the top end of the tank by means of a crane sling hooked to suitable eyelets welded to the top surface of the cover.
5. The forged top cover is locked into place by screwing down on it a forged retainer ring with interrupted buttress threads. This is a quick opening breech lock designed to free the buttress threads after a thirty degree turn of the retainer ring. The pressure transmitted to the top cover by the retainer ring and through the buttress threads to the forged and welded flange is applied perpendicular to two opposing flat surfaces of the buttress thread of the breech lock.

To quote Ewald Schmitz: "In my opinion, the breech lock is the safest possible quick opening locking device. It must be quick opening because testing requires opening the top cover several times a day. It can be opened in a few minutes as compared with about two hours required for opening a bolted closure."

Lester Pfeiffer added: "The alloy steel plate used in the MULTILAYER Vessel costs about 12 cents per pound as compared with 60 cents to 80 cents per pound for an equivalent forged vessel. In addition, the MULTILAYER Vessel is safer because destructive tests to bursting proved that a forged vessel fragments, but the shell of MULTILAYER Vessels tears inductile manner at failure. A inductile tear that initiates in a flaw in one layer will not continue to propagate through the vessel wall. Thus greater safety is obtained at lower cost. These tests have shown that wrapping the layers of a MULTILAYER Vessel prestresses in compression each succeeding inner layer. The precompression is not usually invorporated as a specified design feature."

On acceptance of the CB&I bid by the Naval Laboratory, the proposal became the basis for the final contract. The final plan drawing of the test chamber is shown in Exhibit C-3a. Some of the design calculations are given in Exhibit B-5.

The vessel was then assigned for fabrication.

<u>To the Student:</u>

1. What should be the fabrication procedure of the test chamber?

2. What should the inspection and testing procedure be?

Exhibits

0.1 Scope: This specification covers general requirements for design, fabrication, inspection, testing, and shipping of shop-built CB&I MULTILAYER Pressure Vessels. Specific requirements for a particular vessel are shown on the CB&I Specification Data Sheet which forms a part of this specification.

0.2 Definitions: MULTILAYER Pressure Vessels are welded pressure vessels in which the cylindrical portion is made up of an inner shell and one or more contacting steel layers approximately 1/4" thick. The inner shell is defined as the inner cylinder which forms the pressure tight membrane.

"CB&I" means Chicago Bridge & Iron Company. "Purchaser" means the person or entity entering into a contract with or giving a purchase order to CB&I.

"Structure" or "Vessel" includes only that portion of a facility required to be furnished by CB&I in accordance with the contract or purchase order signed by the Purchaser.

"Data Sheet" means the CB&I Specification Data Sheet for MULTILAYER Pressure Vessels.

0.3 References: Any additional CB&I specifications listed on the Data Sheet form part of this specification. The latest revisions apply. Any additional requirements in the Purchaser's specifications apply only when agreed upon.

References to the Unfired Pressure Vessel Code (UPV Code) of the American Society of Mechanical Engineers (ASME) and to specifications of the American Society for Testing and Materials (ASTM) refer to the latest published revision of or addenda to these documents in effect on the date of the Data Sheet.

1.0 MATERIALS

1.1 All materials shall comply with the material specifications listed on the Data Sheet.

1.2 The inner shell, heads, and openings may be made of a suitable alloy plate, alloy clad plate, or alloy deposited plate to resist corrosion.

2.0 DESIGN

2.1 Section 2.2 gives formulas for determining cylindrical shell thickness and Section 2.3 gives formulas for determining hemispherical head thickness. The stress basis and welding joint efficiency (E) shall be as specified on the Data Sheet.

In these formulas:

t	=	thickness	– in.
P	=	design pressure	– psi
R	=	inside radius before corrosion allowance is added	– in.
S	=	maximum allowable stress corresponding to the design temperature	– psi
E	=	efficiency of the total shell thickness as taken on a section cut by a plane containing the vessel axis and any joint, or efficiency of the total hemispherical head thickness at any joint.	

2.2 Cylindrical shell thickness:

$$t = \frac{PR}{SE - .6P} \qquad \text{UPV Code} \qquad (1)$$

$$t = R\left[\sqrt{\frac{SE + P}{SE - P}} - 1\right] \qquad \text{Lame'} \qquad (2)$$

When special design requirements, i.e. very high pressure, make it desirable to utilize the inherent compressive prestress in the inner shell, the value "SE" may be increased by the amount of this prestress when calculating the required thickness by Formula (2).

2.3 Hemispherical head thickness:

$$t = \frac{PR}{2SE - .2P} \qquad \text{UPV Code} \qquad (3)$$

$$t = R\left[\sqrt[3]{\frac{2(SE+P)}{2SE-P}} - 1\right] \qquad \text{Lame'} \qquad (4)$$

2.4 Fittings: The type of fitting used shall be as designated on the Data Sheet. Reinforcement shall be provided as required by the UPV Code. For openings in MULTILAYER shells the reinforcement shall be integral with the neck of the fitting and/or shall be material provided by additional layer bands having widths equal to at least twice the diameter of the opening.

2.5 MULTILAYER shells shall have holes drilled radially from the outside of the vessel to the inner shell. Each layer plate shall be penetrated by two drilled holes. The holes shall not penetrate the inner shell.

4.0 WELDING PROCEDURE QUALIFICATION

Test plates for the qualification of welding procedures shall be made and tested when required by a change of any of the variables listed in Paragraph Q-11 of Section IX of the ASME Code.

5.0 WELDER QUALIFICATION

Welding shall be performed only by welders and welding operators who have qualified for the procedure to be used as outlined in Paragraph Q-22 of Section IX of the ASME Code.

6.0 RADIOGRAPHIC EXAMINATION

6.1 All longitudinal welded joints of the inner shell (before application of layers) shall be examined throughout their entire length by radiography.

6.2 After the heads or flanges have been welded to the inner shell with welds having a radial thickness equal to the thickness of the inner shell, the circumferential welds shall be given a complete radiographic examination.

6.3 The radiographic technique for **6.1** and **6.2** shall be in accordance with the UPV Code and acceptance standards shall be governed by the requirements of this Code.

6.4 Films required in **6.1** and **6.2** will be retained by CB&I for a period not less than 5 years and will be made available for inspection by the Purchaser upon demand within that period.

7.0 STRESS-RELIEVING

7.1 The completed vessel shall not be stress-relieved.

7.2 The inner shell, head assemblies, and other sub-assembly details may be stress-relieved when specified on the CB&I drawings.

7.3 Sub-assemblies requiring stress-relief shall be stress-relieved after any weld repairs have been made, except that if such parts have been welded into the vessel, peening may be used in place of stress-relief by heating. When peening is done, each weld layer except the first and last shall be peened to minimize shrinkage.

8.0 MACHINING

Inside and outside surfaces of the MULTILAYER shell section will not be machined, unless otherwise specified on the Data Sheet.

9.0 TOLERANCES

9.1 Vessel tolerances shall meet the applicable requirements of the UPV Code unless modified by the CB&I drawings.

9.2 Unless otherwise specified on the drawings, a rough finish to 500 microinch with a round nose tool on all machined surfaces shall be acceptable. All unmachined surfaces shall have a workmanlike finish consistent with good commercial practice.

10.0 TESTING

A hydrostatic pressure test shall be made on the completed vessel at the pressure specified on the CB&I drawings. The test liquid shall be water at 60 °F minimum.

11.0 INSPECTION

11.1 CB&I will allow the Purchaser access to work in process and will furnish reasonable facilities to determine that the work is in accordance with the CB&I drawings and this specification.

11.2 The Purchaser's inspector will arrange to conduct his inspection work and render his decisions within a reasonable time so as not to interfere with the schedule of work.

11.3 All questions relating to inspection and acceptance of the vessel by the Purchaser shall be communicated to the CB&I Quality Control Department.

12.0 DRAWINGS

Unless otherwise specified by the Purchaser, CB&I will furnish as soon as possible after receipt of order and all necessary information, preliminary copies of the CB&I assembly drawings. Upon Purchaser's approval, final assembly drawings will be furnished.

13.0 PAINTING

The vessel will not be painted except when specified on the Data Sheet. Painting, when required, shall consist of one shop coat on the exterior of the vessel unless otherwise purchased by Purchaser.

14.0 SHIPMENT

14.1 The interior of the completed vessel shall be reasonably free from slag, scale, weld droppings, and other foreign matter before shipment.

14.2 All machined surfaces and threads shall be protected during shipment by application of grease or a suitable compound.

14.3 All open nozzles, couplings and manways shall be closed with covers or plugs. All studs shall be left assembled in place on the vessel.

14.4 The vessel will not be boxed, crated, skidded or covered for shipment unless specified on the Data Sheet. Bolts, nuts, spare gaskets and other loose parts will be boxed or crated to prevent loss or damage in transit.

Specification for
HIGH STRENGTH LOW-ALLOY STEEL FORGINGS (5002)

0.1 Scope: This specificotion covers three grodes of high tensile strength, low-alloy steel, heot treated and machined forgings. These forgings ore intended for heads, fittings, covers, plugs and other ports of pressure vessels.

1.0 PROCESS

The steel sholl be mode by the open-hearth, basic oxygen, or electric furnace process.

2.0 MANUFACTURE

When semifinished steel is used to process these forgings, it sholl conform to the requirements of the current edition of the Specification for Alloy Steel Blooms, Billets and Slabs for Forgings, ASTM A 274.

Forging operations may be performed either by hommering, pressing, rolling, extruding, or upsetting. Forging shall be brought as neorly os procticable to the finished shape ond size by hot working throughout the section. Forging sholl be so processed os to couse metol flow during the hot working operotion in the direction most favoroble for resisting the stresses to be encountered in service, when the CB&I purchasing drawing indicates the direction of mojor stresses.

3.0 MACHINING

Unless otherwise specified, oll surfaces of the forging shall be mochined to o surface roughness not exceeding 500 microinches.

Specification for
HIGH STRENGTH LOW-ALLOY STEEL FORGINGS (5002)

6.0 MECHANICAL PROPERTIES

The material shall conform to the requirements in **Table 6.0** when tested in accordance with the current edition of Methods and Definitions for Mechanical Testing of Steel Products, ASTM A 370.

Table 6.0 Tensile Requirements

	Grade A	Grade B	Grade C
Tensile Strength, min, psi	80,000 to 100,000	85,000 to 105,000	95,000 to 115,000
Yield Strength, min, psi*	51,000	56,000	65,000
Elongation in 2 in., min	18.0%	18.0%	18.0%
Reduction of Area, min	35.0%	35.0%	35.0%

*0.2% offset or 0.5% extension under load.

7.0 TEST SPECIMENS

Tension test specimens shall be tangential, unless impracticable for small forgings or otherwise specified, and shall be taken from material in the heat treated condition. The test specimen shall be taken from a representative forging or from a prolongation of the forging as indicated on the CB&I drawing or in ASTM A 370.

Unless otherwise specified, one tension test shall be made from each heat in each heat treatment charge.

When specified, one tension test shall be make for each forging.

8.0 RETEST

If the results of the mechanical tests do not conform to the requirements specified, the manufacturer may reheat treat the forgings, but not more than three additional times. Retests shall be made in accordance with with Section **7.0.**

9.0 QUALITY

Forgings shall be free from injurious defects and shall have a workmanlike finish.

10.0 REPORT OF TEST

Furnish a certified test report showing chemical composition, mechanical properties and heat treatment practice to the Purchasing Department at the Chicago Bridge & Iron Company office from which the order was received.

11.0 MARKING

Each forging shall be legibly stamped with the name of the manufacturer, the manufacturer's test identification number, the identification number **5002** followed by the letter **A**, **B**, or **C** indicating the grade specified, and the CB&I piece mark.

Specification for HIGH STRENGTH LOW-ALLOY STEEL PLATES (1146)

0.1 Scope: This specification covers high tensile strength, low-alloy steel plates of flange quality, made to fine grain practice, for use in fusion welded tanks and pressure vessels. Plate thicknesses range from .180 thru .580 in. for grade A.

..0 GENERAL CONDITIONS FOR DELIVERY

Material furnished under this specification shall conform to the applicable requirements of the current edition of the Specification for General Requirements for Delivery of Rolled Steel Plates of Flange and Firebox Qualities, ASTM A 20.

2.0 PROCESS

The steel shall be made by the open-hearth, basic oxygen, or electric furnace process.

4.0 TENSILE PROPERTIES

The material as represented by tension test specimens shall conform to the requirements in Table 4.0.

▶ Table 4.0 Tensile Requirements

	Thickness Range, in.	
	.180 thru .375	Over .375 thru .580
Tensile Strength, psi	105,000 to 135,000	100,000 to 130,000
Yield Strength, min, psi	70,000	66,700
Elongation in 2 in., min	22.0%	22.0%

5.0 BENDING PROPERTIES

Bend test specimens shall stand being bent cold thru 180° to an inside diameter that is 3 1/2 times the thickness of the material, without cracking on the outside of the bent portion.

6.0 TEST SPECIMENS

Test specimens shall be prepared from material in the as-rolled condition.

7.0 NUMBER OF TESTS

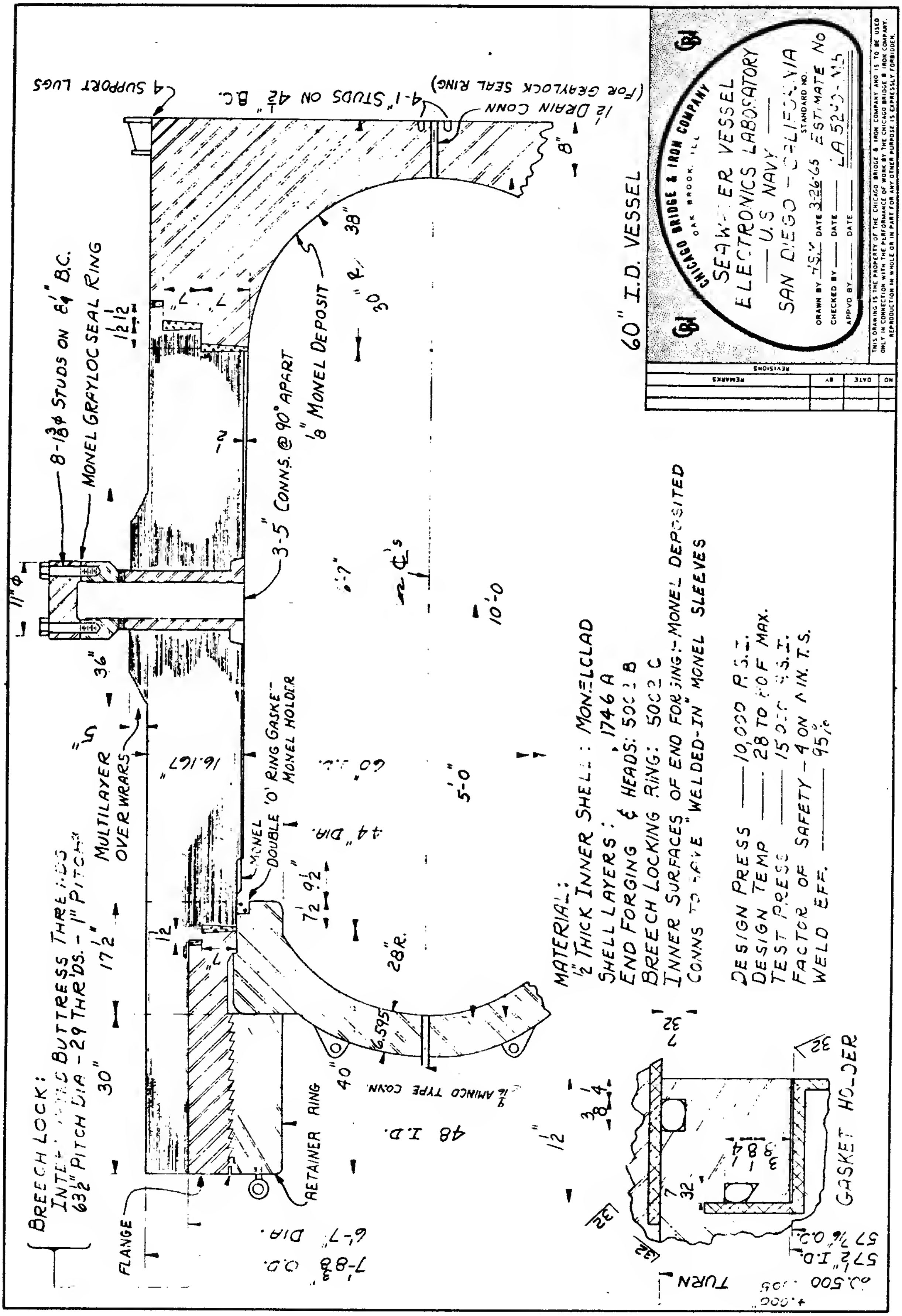
One tension test and one bend test shall be made from each plate as rolled.

8.0 REPORT OF TEST

Furnish a certified test report showing chemical composition, and mechanical properties to the Purchasing Department at the Chicago Bridge & Iron Company office from which the order was received.

9.0 M/ KING

As provided in ASTM A20, each plate shall be painted or stenciled with the letters "NIV" in addition to the regular marking.


CHICAGO BRIDGE & IRON COMPANY
OAK BROOK, ILL.
SEAWATER VESSEL
ELECTRONICS LABORATORY
U.S. NAVY
SAN DIEGO — CALIFORNIA
60" I.D. VESSEL
4 SUPPORT LUGS
4-1" STUDS ON 42" B.C.
1/2" DRAIN CONN
(FOR GRAYLOCK SEAL RING)
8-1 3/8 Ø STUDS ON 8 1/4" B.C.
MONEL GRAYLOC SEAL RING
3-5" CONNS. @ 90° APART
1/8" MONEL DEPOSIT
30" R.
38"
36"
MULTILAYER OVERWRAPS
MONEL DOUBLE 'O' RING GASKET MONEL HOLDER
44" DIA.
10'-0
5'-0
28" R.
48" I.D.
RETAINER RING
FLANGE
BREECH LOCK:
BUTTRESS THREADS
29 THR'DS. - 1" PITCH
30"
6'-7" DIA.
7'-8 3/8" O.D.
1/4" AMINCO TYPE CONN.
MATERIAL:
1/2" THICK INNER SHELL : MONELCLAD
SHELL LAYERS : 1746 A
END FORGING & HEADS: 5002 B
BREECH LOCKING RING: 5002 C
INNER SURFACES OF END FORGING:- MONEL DEPOSITED
CONNS TO HAVE "WELDED-IN" MONEL SLEEVES
DESIGN PRESS — 10,000 P.S.I.
DESIGN TEMP — 28 TO 80 F MAX.
TEST PRESS — 15,000 P.S.I.
FACTOR OF SAFETY — 4 ON MIN. T.S.
WELD EFF. — 95%
GASKET HOLDER
57 1/2" I.D.
TURN

SPECIFICATION DATA SHEET for MULTILAYER* PRESSURE VESSELS

Vessel to be constructed in accordance with CB&I MULTILAYER Pressure Vessel Standard 4400-1 (Specification MLS-30).
Vessel will be insurance inspected but not code stamped.
* Trademark of A.O.Smith Corporation licensed to Chicago Bridge & Iron Company.

MULTILAYER VESSEL DATA

REF DWGS CB&I Dwgs. 1,2,4,5,6, 7 & 8

DESIGN CONDITIONS:
- DESIGN PRESSURE 10,000 PSI
- DESIGN TEMPERATURE 28 to 80 °F
- HYDRO TEST PRESSURE 15000 PSI
- WORKING PRESSURE ____ PSI
- WORKING TEMPERATURE ____ °F
- CORROSION ~~ALLOWANCE~~ barrier 1/8" Monel
- WELDING EFFICIENCY 95 %
- STRESS BASIS 4 on Min Ult. Tensile

JACKET: REQD YES ☐ NO ☒
- DESIGN PRESSURE ____ PSI
- DESIGN TEMPERATURE ____ °F

DESCRIPTION:
- INSIDE DIA 60"
- LENGTH 10'0 Inside
- SHELL THK 16.507
- HEADS: 2:1 ELLIP ☐ HEMI ☒
- TOP HEAD THK 7.00 MIN
- BOT HEAD THK 7.53 MIN

CONSTRUCTION:
- STRESS-RELIEVE LONG. JT INNER SHELL ONLY BEFORE WRAPPING YES ☒ NO ☐
- RADIOGRAPH LONG. JT INNER SHELL ONLY BEFORE WRAPPING YES ☒ NO ☐
- FITTING RATING ____
- FTG TYPE Special
- FTG FACING Grayloc

MATERIAL: 1/8 Monel Clad on
- INNER SHELL A225 GR B
- SHELL LAYERS 1146 (CB&I)
- TOP HEAD 5002 B (CB&I)
- BOT HEAD 5002 B do
- TOP FLANGE 5002B do
- BOT FLANGE ____
- ~~XXXXX~~ Breech Lock 5002B (CB&I)
- FITTINGS 5002B (CB&I)
- JACKET ____
- SUPPORTS A283 GR C
- INTERNALS ____
- STUDS ASTM A193 GR B7
- NUTS ASTM A194 GR 2
- GASKETS Neoprene "O" rings & silver plated monel

EQUIPMENT FURNISHED BY CB&I

- BOLTING FOR NOZZLES YES ☒ NO ☐
- BOLTING & GASKETS FOR MANHOLES AND BLIND FLANGES YES ☒ NO ☐
- NO. OF SETS OF GASKETS ____
- VESSEL PAINTED YES ☒ NO ☐
- SUPPORTS YES ☒ NO ☐
- TYPE Bottom Head
- MANHOLE DAVITS YES ☐ NO ☒
- LADDER & PLAT CLIPS YES ☐ NO ☒
- INSUL RINGS OR CLIPS YES ☐ NO ☒

TYPE OF VESSEL: Test Chamber
CAPACITY:
PURCHASER: U.S.Navy Electronics Lab.
NO. REQD: 1
DESTINATION: San Diego, California

REV	DATE	BY	REMARKS
1	11-19-65	HBJ	Supports, gaskets

	DATE	BY	
MADE	10-1	TAG	CHICAGO BRIDGE & IRON COMPANY
EST. NO. 9-3201			

Approved: EWV

CBI STANDARD

Lamé Design Calculations
MULTILAYER SHELL AND HEMISPHERICAL HEAD

STANDARD 4402-1-1
Distr 7a Page 1
4-30-64

DESIGN CONDITIONS

P = 10,000 psi
T = 28 TO 80 °F
E = .95
ID = 60.0 "

Stress Basis = 4 ON UTS
Corrosion Allowance = NONE (CA)
Filler Layers (FL) No ☐ Yes ☑ t_{FL} = TWO @ .1875 "
Filler Layer Channeled No ☑ Yes ☐

	Layers	Inner Shell	Head
Material	1146 (CB&I)	A225B + MONEL	5002B (CB&I)
UTS @ Room Temp	105000	75000	85000
YS @ Room Temp	70,000	43000	56000
S @ 80 °F	26250 (S_L)	18750 (S_i)	21250 (S_H)
Thickness (less clad)	—	(1/2 - 1/8) (t_i)	—

1.0 SHELL UG 27: .385 SE = .385 × 26250 × .95 = 9620 < 10,000 ∴ USE LAMÉ

1.1 When inner shell is included in thickness required:

$$CF = t_i \left[\frac{S_L - S_i}{S_L}\right] + t_{FL} = (.375)\left[\frac{(26250) - (18750)}{(26250)}\right] + (.375) = \underline{.482}\ "$$

1.2 When inner shell is not included in thickness required:

~~CF = $t_i + t_{FL}$ = ( ) + ( )~~ = ______ "

1.3

$$t_s = \frac{ID}{2}\left[\sqrt{\frac{S_LE+P}{S_LE-P}} - 1\right] + CF + \cancel{CA}^{\,0}$$

S_LE = (26250) (0.95) = 24938 psi

$$\sqrt{\frac{S_LE+P}{S_LE-P}} = \sqrt{\frac{(24938)+(10000)}{(24938)-(10000)}} = \sqrt{(2.339)} = \underline{1.5294}$$

$$t_s = \frac{(60.0)}{2}\left[(1.5294) - 1\right] + (.482) + (.125) = \boxed{16.489''\ (t_s)}$$

15.882 CLADDING

DOES NOT GOVERN

2.0 HEMISPHERICAL HEAD UG 32f: .665 SE = .665 × 21250 × .95 = 13580 > 10000

BOTTOM HEAD ONLY

$$t = \frac{PL}{2SE - .2P} = \frac{10{,}000 \times 30}{2 \times 21250 \times .95 - 2000} = 7.818 + .125 = 7.943 \text{ in.}$$

CLADDING

AT WELD SEAM

$$t = \frac{PL}{2SE - .2P} \quad \frac{10{,}000 \times 30}{2 \times 21250 - 2000} = 7.407 + .125 = 7.532$$

AT BOTTOM

Vessel: EXPER. TEST CHAMBER
Customer: USNEL
Location: SAN DIEGO

Estimate: ______
Contract: 9-3201
By: T.G. Date: 7-8-65
MB.

1/15

CHICAGO BRIDGE & IRON COMPANY OAK BROOK, ILLINOIS

Approved: RW

CBI STANDARD

Lamé Design Calculations
MULTILAYER SHELL AND
HEMISPHERICAL HEAD

STANDARD 4402-1-1

Distr 7a

Page 1

4-30-64

DESIGN CONDITIONS

P = 10000 psi

T = 28 TO 80 °F

E = .95

ID = 60.0 "

Stress Basis = 4 ON UTS

Corrosion Allowance = NONE (CA)

Filler Layers (FL) No ☐ Yes ☑ t_{FL} = TWO @ .1875

Filler Layer Channeled No ☑ Yes ☐

	Layers	ASTM Inner Shell B127	Head
Material	1146 (CB&I)	MONEL ONLY	5002B (CB&I)
UTS @ Room Temp	105000	70,000	85000
YS @ Room Temp	70000	28000	56000
S @ 80 °F	26250 (S_L)	17500 (S_i)	21250 (S_H)
Thickness (less clad)	—	(1/2 - 1/8) (t_i)	—

1.0 SHELL

1.1 When inner shell is included in thickness required:

$$CF = t_i\left[\frac{S_L - S_i}{S_L}\right] + t_{FL} = (.375)\left[\frac{(26250) - (17500)}{(26250)}\right] + (.375) = .500"$$

~~1.2~~ When inner shell is not included in thickness required:

~~$CF = t_i + t_{FL} = (\quad) + (\quad)$~~ = ______"

1.3

$$t_s = \frac{ID}{2}\left[\sqrt{\frac{S_L E + P}{S_L E - P}} - 1\right] + CF + CA \qquad S_L E = (26250)(.95) = 24938 \text{ psi}$$

$$\sqrt{\frac{S_L E + P}{S_L E - P}} = \sqrt{\frac{(24938) + (10000)}{(24938) - (10000)}} = \sqrt{(2.339)} = 1.5294$$

$$t_s = \frac{(60)}{2}\left[(1.5294) - 1\right] + (.500) + (.125) = \boxed{16.507\ (t_s)}$$

15.882

USE

Vessel: EXPER, TEST CHAMBER

Customer: USNEL

Location: SAN DIEGO

Estimate:

Contract: 9-3201

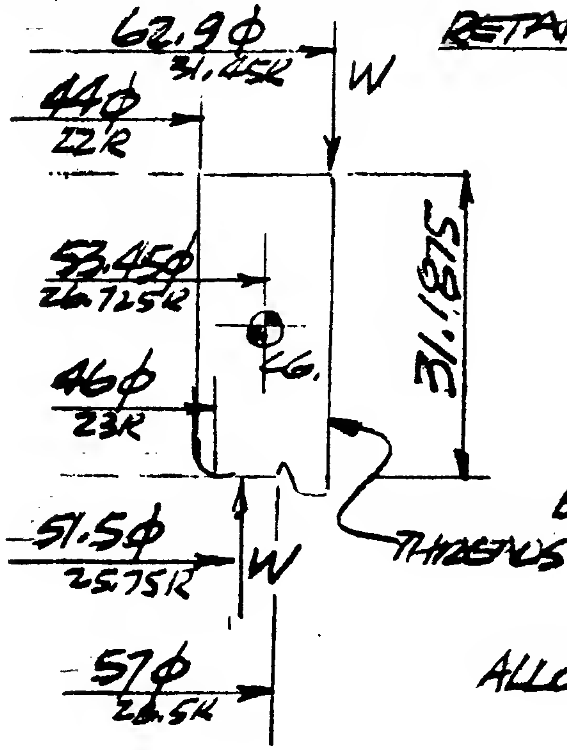
By: TAG NB.

Date: 7-8-65

2/15

CHICAGO BRIDGE & IRON COMPANY OAK BROOK, ILLINOIS

CHICAGO BRIDGE & IRON COMPANY CENTRAL REGION ENGINEERING DEPT.



RETAINER RING
MATL: C.B.&I 5002B

$W = 10{,}000 \times \frac{\pi}{4} \times 60^2 = 28.274 \times 10^6$ #

BEARING AREA

$\pi/4\,(57)^2 = 2551.8$

$-\ \pi/4\,(46)^2 = 1661.9$

$889.9\ in^2$

BEARING STRESS $= \frac{28.274 \times 10^6}{889.9}$

$= 31\,770$ psi

ALLOW. BEARING STRESS =
$1.6 \times 21250 = 34{,}000$ psi

TWISTING MOMENT ABOUT C.G./STRESS

$$M_t = \frac{28.274 \times 10^6 \times 5.7}{53.45\pi} = .95975 \times 10^6\ \frac{in\#}{in}$$

62.9
51.5
11.4
5.7

$$M = M_t\,(26.725) = 25.652 \times 10^6\ in\#$$

$$S_{max} = \frac{6 \times 25.652 \times 10^6}{31.188^2 (22) \log\left(\frac{62.9}{44}\right)}$$

$S_{max} = 20{,}100$ psi

$\ln$ 1.4295
.3573

21250 ALLOWABLE
FOR 5002B

SHEAR STRESS

63.5 NOM PITCH DIA BUTTRESS THREADS (5°) 1" PITCH.
SHEAR AREA PER THREAD = 1.000 − .183 = .817 AT
62.945 DIA FOR 30 THREADS WITH 50% ENGAGEMENT

SHEAR STRESS $= \frac{28.274 \times 10^6}{62.945 \times \pi \times .817 \times 30/2} = 11670$ psi

ALLOW SHEAR $= 0.8 \times 21250 = 17{,}000$ psi

Subject _____ Cont. G-3320 Date 7/23 By TAG Sht 3 of 15

CHICAGO BRIDGE & IRON COMPANY CENTRAL REGION ENGINEERING DEPT.

5" NOZZLE MATL: C.B.&I 5002B FORGING W/ 1/8 THK MONEL LINER

$$t_w = \frac{5.0}{2}\left[\sqrt{\frac{21250+10,000}{21250-10,000}} - 1\right]$$ FOR $D > 3SE$ AND $E = 1.0$

$$= 2.5\left[\sqrt{\frac{31250}{11250}} - 1\right]$$

$$t_w = 2.5(.6667) = 1.666 \approx 1\tfrac{11}{16}$$

NOZZLE O.D. = 5.25 + 3.332 = 8.58; USE $8\tfrac{5}{8}$ O.D.

MAX. DIAMETRAL CLEARANCE BETWEEN NOZZLE AND VESSEL PENETRATION = 0.030 (FIG N-462.4(d)), SECTION III ASME

FOR REINFORCING $d = R_n + t_n + t$
$= 2.5 + 1.687 + 16 = 20.1875$

AREA REMOVED = 8.655 × 16.507 = 142.87

OVERLAPS REQ'L TO PROVIDE REINF AREA:

$$t = \frac{.5A}{(20.1875 - 4.3125)} = \frac{71.166}{15.875} = 4.484 \text{ in}$$

END FORCE ON NOZZLE: $\pi/4\,(8.75)^2 \times 10,000$
$= 601\,320^{\#}$

ALLOW SHEAR IN WELD $= .6(21250)(.95)$
$= 12,100$ PSI

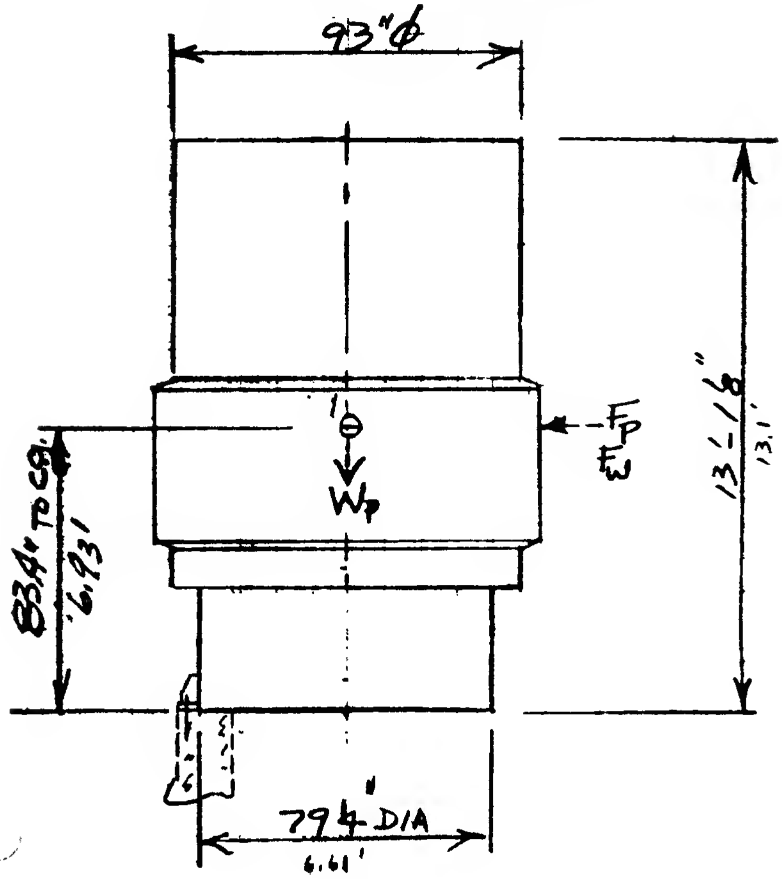
DEPTH OF WELD GROOVE $= \frac{601320}{8.625\pi \times 12,100} = 1.835$

USE $2\tfrac{1}{4}$ DEEP GROOVE

PROVIDE 16.507 + 4.484 = 20.99 SHELL THK @ NOZZLE

5" SHELL NOZZLE Subject Cont. 9-5201 Date 7/23 By TAS Sht 4 of 15

CHICAGO BRIDGE & IRON COMPANY CENTRAL REGION ENGINEERING DEPT.



D.L. OF VESSEL, $W_p = 210^K$

WIND LOAD, F_W

$F_W = 8' \times 13.1' \times 20^{\#}/' = 2100^{\#}$

$M_{WIND} = 2.1^K\left(\frac{13.1}{2}\right) = 13.72'^K$

SEISMIC LOAD

UNIFORM BLDG CODE SECT 2314, 1964 VOL I

F_p = LATERAL FORCE

$= Z C_p W_p$

$= (1)(0.20)\ 210^K$

$F_p = 42^K$

$M_{SEISMIC} = 42^K(6.93') = 291\ '^K$

RESISTING MOMENT, $M_R = 210^K(3.30') = 693\ '^K > M_{SEISMIC}$

ALSO $2/3\ M_R > M_{WIND}$

NO ANCHOR BOLTS REQ'D BUT

TO PROVIDE STABILITY FOR PIPING, ASSEMBLY AND DISASSEMBLY OF CLOSURE, USE 4 LUGS FOR (NOM.) 1 1/2" ANCHOR BOLTS ON OUTSIDE OF BOTTOM HEAD.

PROVIDE FOUNDATION FOR VESSEL UNDER BOTTOM HEAD.

Fabrication of a Seawater Test Chamber

at

Chicago Bridge and Iron Company (C)

The fabrication of this test chamber, as well as many of the other products of the Company, is a "one of a kind" project. Consequently, the quality of workmanship depends mainly on manual control of suitable or standard machine tools rather than production line equipment.

The general procedures used in the fabrication of the test chamber, in the order which they are performed, are as follows:

1. Layout of plate work.
2. Cutting and scarfing.
3. Rolling and forming.
4. Small pieces such as ports for instrumentation, filling, draining, and controlling pressure are made in detail shops in side bays.
5. Welding.
6. Final assembly: shell to shell, connections to head, head to shell.
7. Attachment of bottom skirt.

This case was prepared by Professors Karl H. Otte and Otto E. Widera of the University of Illinois at Chicago Circle during the 1967 Summer Institute on Case Methods. The Institute was supported by the National Science Foundation and held at the University of Illinois in Chicago. The cooperation of Messrs. Roger Reedy, Lester Pfeiffer and Ewald Schmitz of CB&I is gratefully acknowledged.

8. Adequate non-destructive radiographic inspection is made of the girth seams and the longitudinal seams are Magna-flux with magnetic particles. Forgings are inspected for cracks, porosity, and imperfections by ultra-sonic methods.

9. The final pressure test at 150% of design pressure for the normal design stress.

Exhibit C-1 shows the Manufacturer's Data report and describes the pressure testing of this vessel as witnessed by an inspector employed by CB&I and an inspector from the Hartford Steam Boiler Insurance and Inspection Company. It is required by law that the copies of this report be held in the files of the manufacturer, the purchasers and the Hartford Company for at least five years from the date of the test. This is considered a reasonable time period for uncovering any defects in the vessel.

Although pressure vessels may be expected to have a normal life of at least twenty years, they are subjected to frequent internal and external inspections. These inspections are made to determine whether corrosion or other deterioration or damage requires repair or condemnation of the vessel.

Exhibit C-2 gives the General Instructions for Top Cover Closure and describes the exact steps to follow in Assembly and Disassembly of the Top Cover Closure. It is essential that these steps be followed carefully in order to avoid questionable procedures that may nick, scratch, or damage the cover and result in failure of the vessel.

To the Students:

1. Can you suggest any improvements in this method of sealing the cover?

2. How do you think that your suggestion, if any, will affect the cost of the pressure vessel?

Note to the Student: Exhibit
should be studied and analyzed in detail. After you have studied them, you should be able to discuss the following questions:

1. What changes or improvements can you sugest?
2. Why do you think they are desirable?
3. How would they affect the cost?

Exhibit C-4 is a set of photographs showing the Top Cover being lowered into place. Note: the light colored scuff blocks for preventing damage to the cover and buttress threads while the cover is being lowered into place. Exhibit C-5 is a set of photographs showing the Retaining Ring being lowered into place above the Top Cover. Note: the relative positions of the buttress threads of the Ring and Breech. Neither of these series of photographs show the gaskets for sealing the cover and ring. Nor do they show clearly the small pitch of the thread which produces a wedging and sealing action. Exterior views of the vessel are shown in Exhibit C-6.

Exhibits

Exhibit C-1

ECL 92C

GO 146 REV 9-63

CHICAGO BRIDGE & IRON COMPANY

MANUFACTURER'S DATA REPORT for MULTILAYER PRESSURE VESSEL

1 Manufactured by Chicago Bridge & Iron Company, Chicago, Illinois Year 1966 CB&I Contract N123 ~~(953)~~ Tape

2 Manufactured for U.S. Navy Electronics Lab., SanDiego, Calif. Purchaser's Order No. 53207A

3 Mfr's No. M244 Inspection Agency No. - State & State No. -

4 Shell: Inside Diameter 60 Length 10'-0 ins. Total Thickness 16.51" Joint Eff 95 %

Inner Shell: Thickness 1/2 " Material SA225B FB Clad W/1/8 Monel and solid Monel (SB127) Min T.S. 75000 70000 psi

Layers: 5 @ 1/4 " & 49 @ 9/32 " Material CB & I 1146 Min T.S. 105,000 psi

5 Long. Weld Joints: Inner Shell – Double Butt Layers – Single Butt Backed up by Adjacent Layers

6 Circumferential Weld Joints: Double Butt No. of Multilayer Shell Courses 1

7 Jacket: Inside Diameter - Length Thickness

Longitudinal Joints Circumferential Joints

8 Heads: Top or One End: Thk 6-7/8* Matl CB&I 5002B Description HEMIS (Removable)

Bot or Opp End: Thk 8* " Matl CB&I 5002B Description HEMIS, Inside

If removable, bolting or method of fastening Buttress interrupted Threaded retaining ring Matl CB&I 5002B

9 Radiographic Inspection: Inner Shell Joints: Long. – 100% Circum. – 100%

Magnetic particle inspect each layer long. seam

10 Parts Stress-Relieved	Controlling Thickness	Temperature	Holding Time
Clad inner shell	3/4 in.	1150 °F	3/4 Hr
Bottom & Top Head	3/4 in.	975 °F	4 Hr
5" Shell Nozzles	1/8 Monel overlay	975	4

11 Fittings:	Location	No.	Size	Material of Neck or Reinforcing
Nozzles	Heads	2	9/16", 1½"	SB164 (Monel), Intergral
Nozzles	Shell	3	5"	CB&I 5002B & 1146
Handholes or Sightholes				
Manholes	Heads			
Manholes	Shell			

12 Max Allowable Working Pressure Atm Temp (New & Cold) 10,000 psi Circum Design Stress 26250 (layers) psi

13 Hydrostatic Test Pressure 15,000 psi Circum Test Stress 39375 " psi

14 Vessel Constructed for Pressure of 10,000 psi at 28 to 80 °F Corrosion ~~Allowance~~ Barrier 1/8"Monel

15 Vessel Name or Purpose: Seawater Test Vessel Type: Horiz ☐ Vert X

Remarks: *Does not include 1/8 Monel weld deposit

We certify the above data to be correct and that all details of design, material, construction, and workmanship on this MULTILAYER Pressure Vessel conform to CB&I Standard 4400-1 (Specification MLS-30).

Date 3-14-67 Signed [signature] for Chicago Bridge & Iron Company

I have inspected the Multilayer Pressure Vessel described in this Data Report and state that to the best of my knowledge and belief this vessel conforms to CB&I Standard 4400-1 (Specification MLS-30).

Date 3-14-67 Signed:† [signature] INSPECTOR Hartford Steam Boiler I & I Co. of Conn. INSPECTION AGENCY

† NOTE: By signing this Manufacturer's Data Report neither the inspector nor his employer makes any warranty, expressed or implied, concerning the object described. Furthermore, neither the inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

GENERAL INSTRUCTIONS
FOR
TOP COVER CLOSURE

A double "O" ring gasket closure is provided on the periphery of the top cover. Sealing of the closure is obtained by the rotation of a gasket holder ring (by unbalanced differential pressure both radially and axially) which contains the grooves for two rubber "O" rings, the "O" rings provide a static seal which in turn permits the rotation of the gasket holder. The seal is maintained by the pressure.

Care must be taken during all phases of assembly that all internal machined surfaces are clean and free from foreign materials, nicks, and scratches.

Thread lubricant shall be moly kote or equal and shall be free of all foreign material.

A. EQUIPMENT NEEDED:

1. All vessel parts are assumed furnished, inspected and ready for assembly.
2. Provide cleaning solvent and lubricants. Thread lubricant shall be moly kote or equal.
3. Threaded ring must be assembled using a crane scale and hand chain hoist. Ring weight is about 8 tons.

ASSEMBLY PROCEDURE:

1. Clean threads and gasket surfaces of top end flange. Inspect gasket sealing surfaces for nicks and scratches.
2. Apply thread lubricant to threads in vessel.
3. Clean top head gasket areas.
4. Lower top head assembly with bearing pads in slots of end flange. Care must be taken in this operation so that the gasket or threads are not damaged.

<u>NOTE</u>: 9/16 ø connection must be open to allow entrapped air in vessel to escape.

5. Clean and lubricate retainer ring, threads and bottom bearing surface.
6. Using chain hoist and crane scale, lower ring into end flange slots. Orient retainer ring so retainer ring locking bracket is 30° counterclockwise from end flange locking bracket.

NOTE: Record weight of plug prior to assembly. Maintain as close as possible, the ring weight on the scale throughout the threading operation. With the retainer ring resting on the bottom thread of the flange, rotate the retainer ring 30° clockwise, lock with locking device.

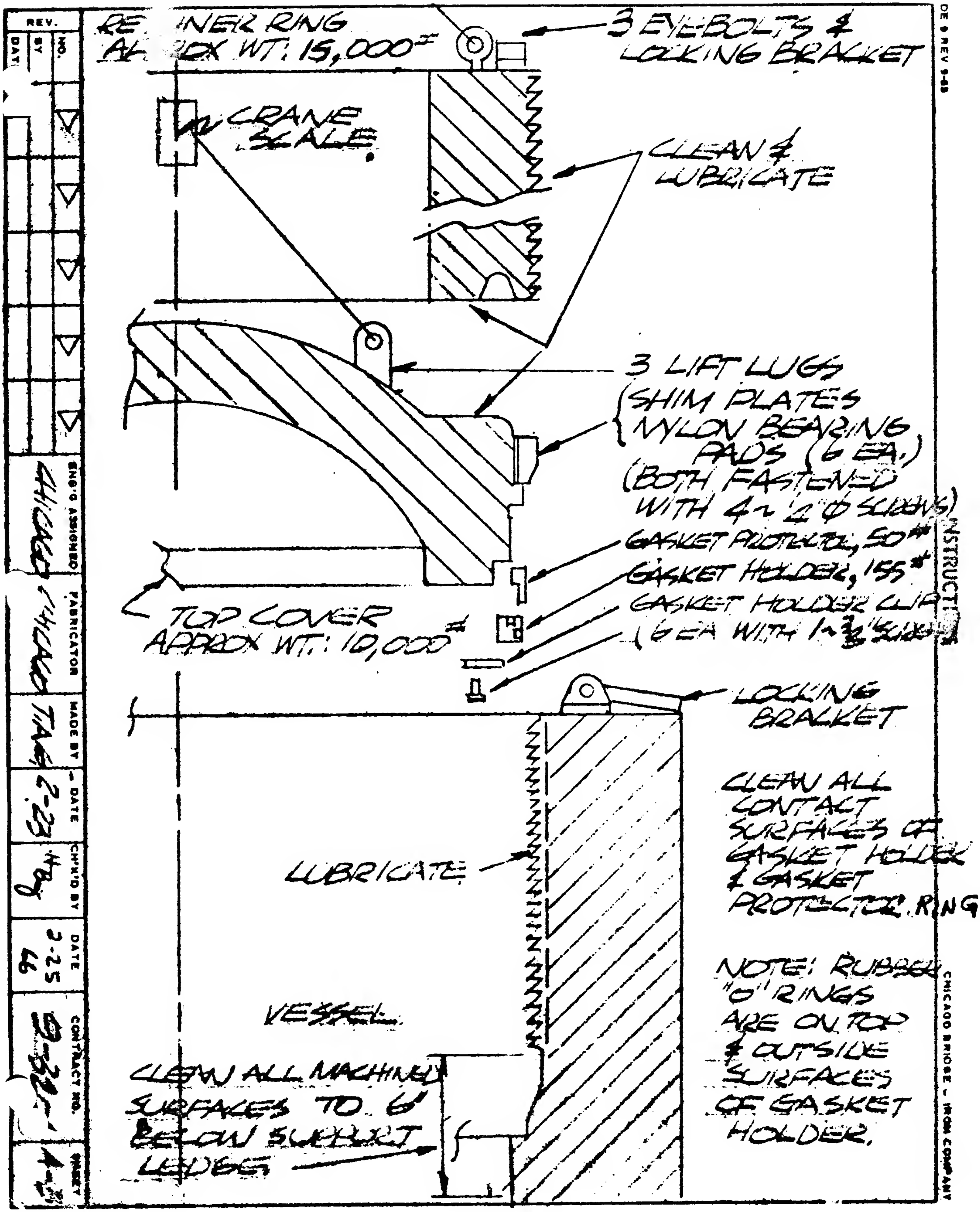
REV. | NO. | BY | DATE
ENG'G ASSIGNED: Shockey
FABRICATOR: CHICAGO
MADE BY: Tiple
DATE: 2-24
CHK'D BY: RW
DATE: 2-25-79
CONTRACT NO.: [illegible]
SHEET: [illegible]

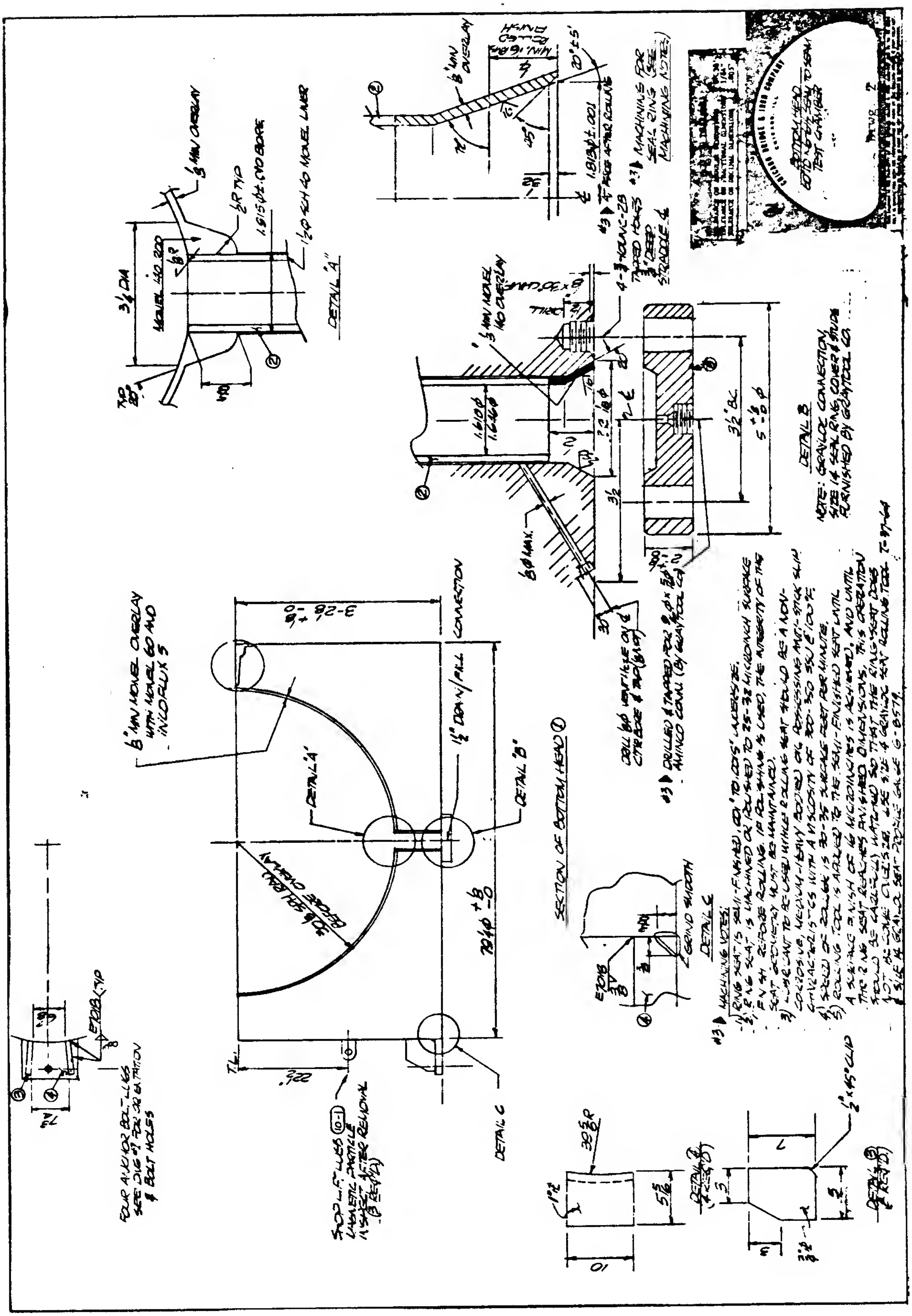
REV. NO.	BY	DATE

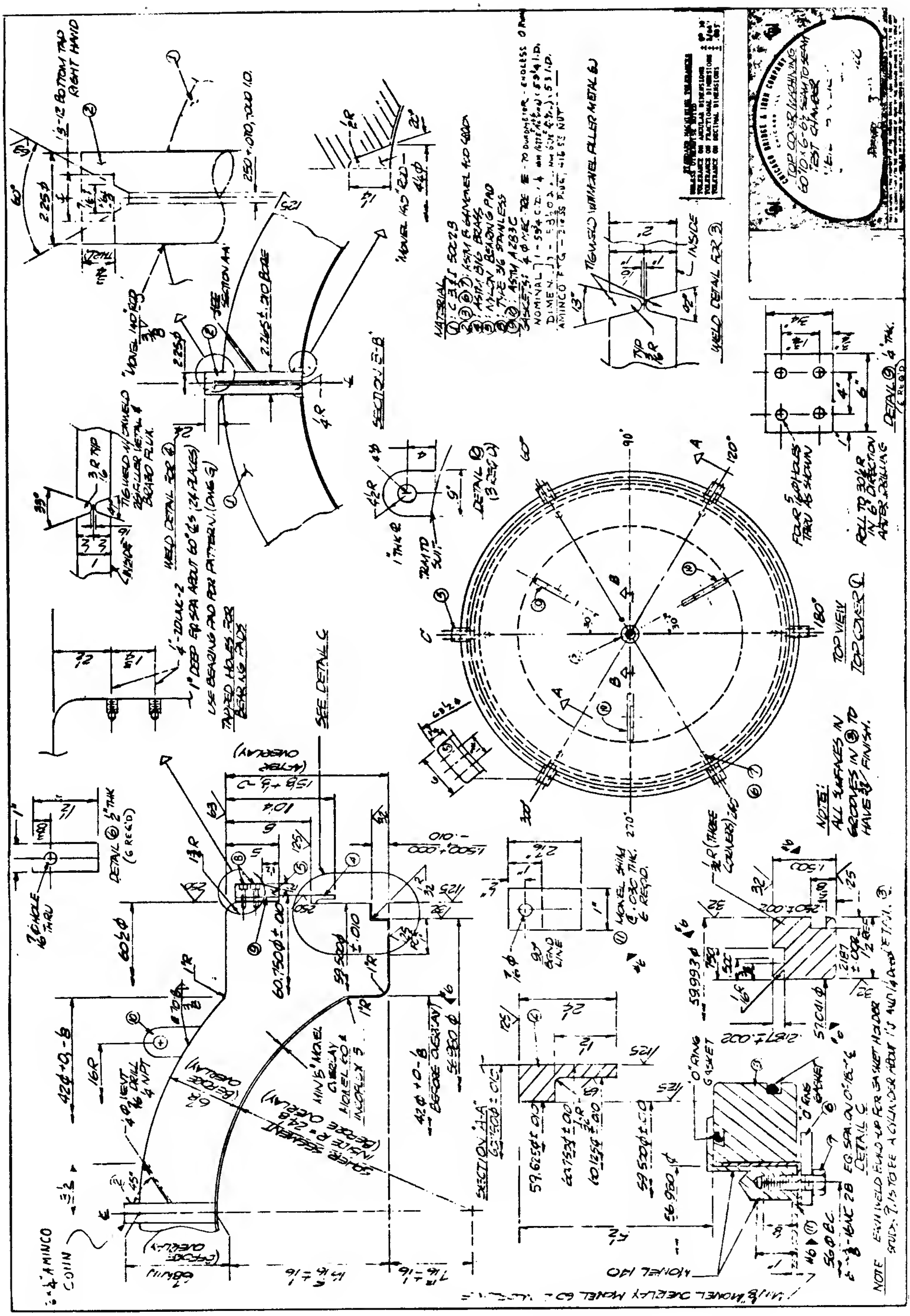
ENG'G ASSIGNED	FABRICATOR	MADE BY	DATE	CHK'D BY	DATE	CONTRACT NO.	SHEET
CHICAGO	CHICAGO	TAG	2-24	HB	2-25 66	[illegible]	[illegible]

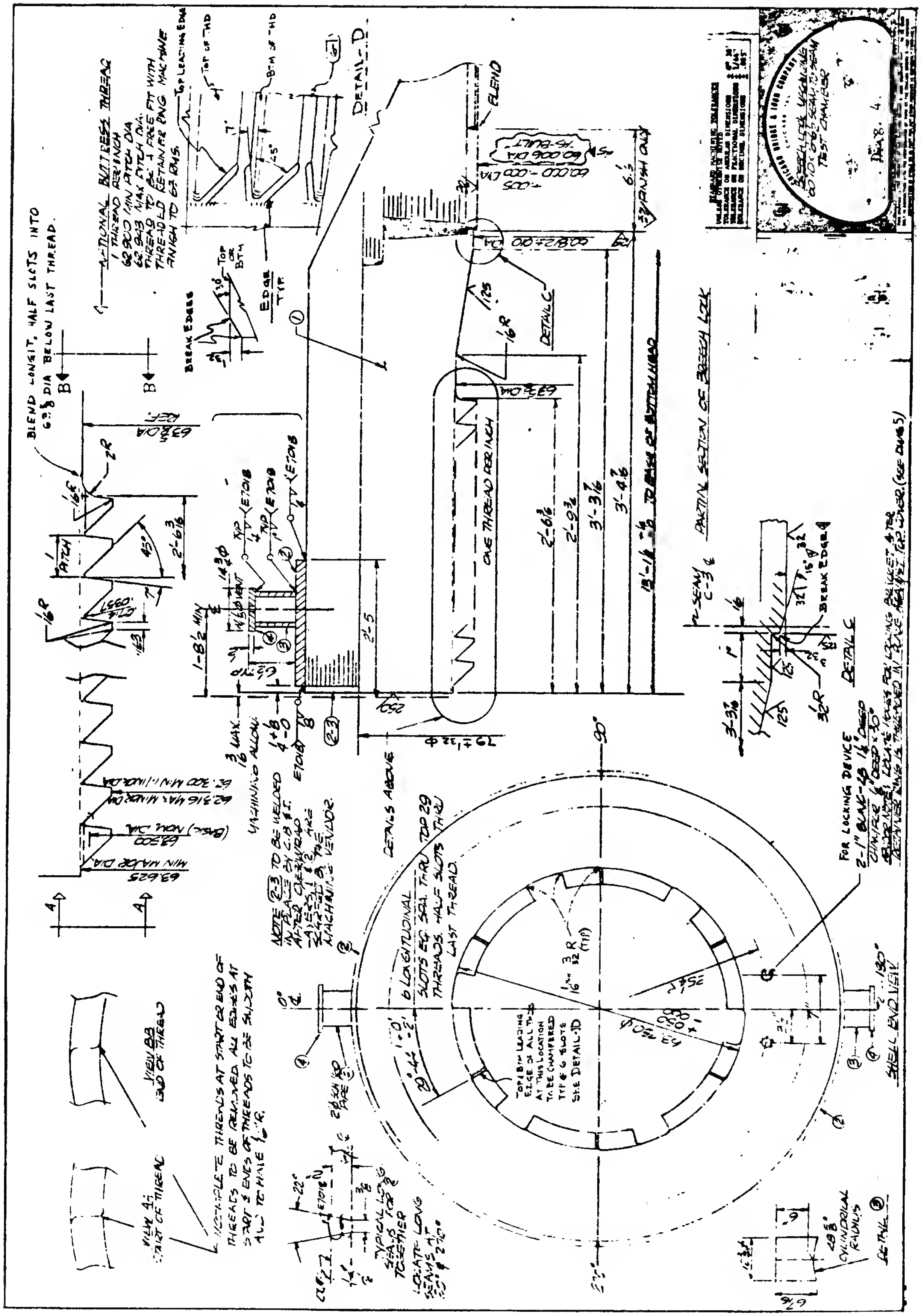
C. DISASSEMBLY PROCEDURE:

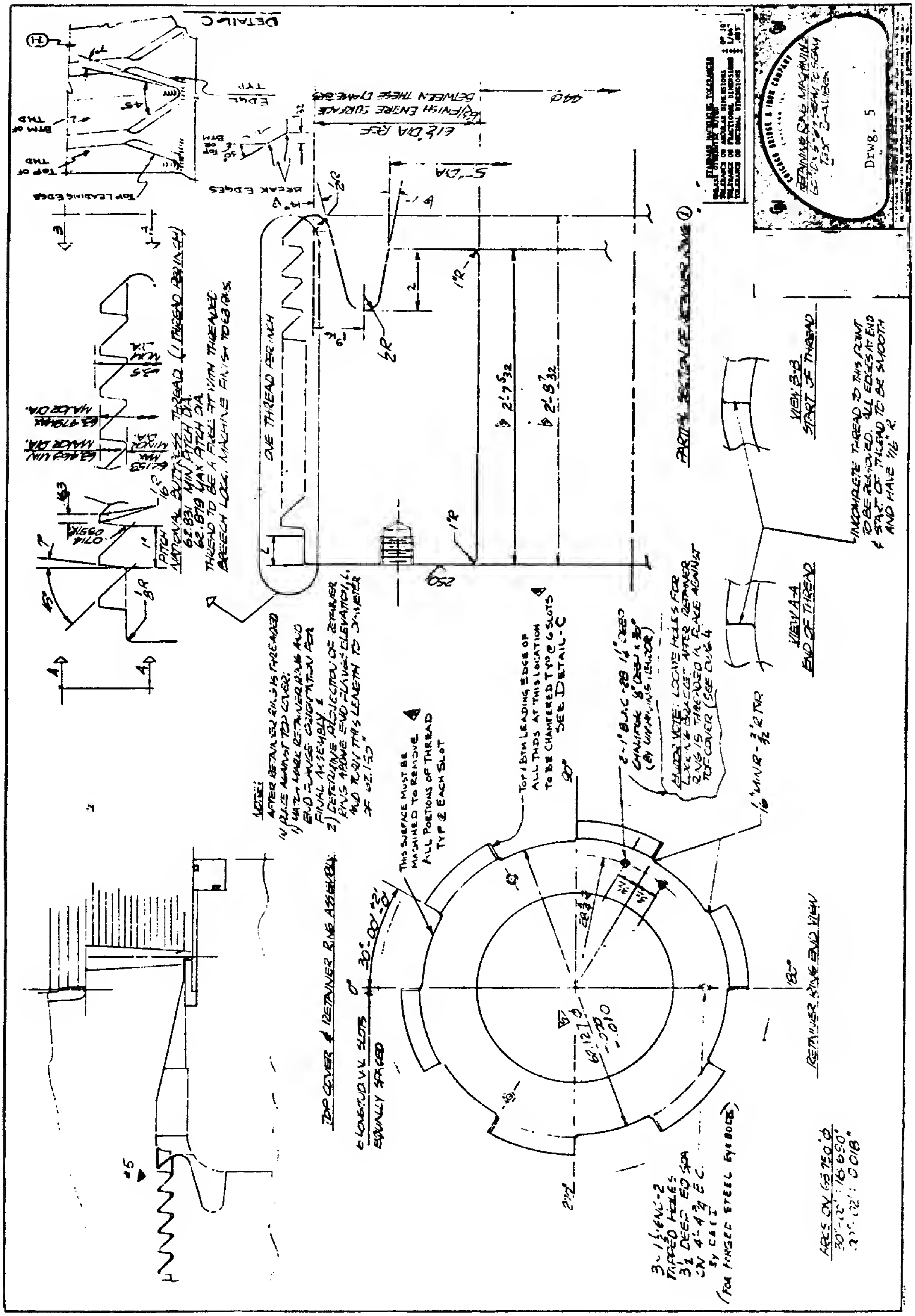
1. Remove locking bar.
2. Attach lifting rig, hand chain hoist, and crane scale. Pull up with hoist until recorded weight of the threaded ring shows on scale. Maintain this weight reading on the scale as the ring thread is rotated counterclockwise 30° into the longitudinal slots of the end flange. Lift & remove retainer ring.
3. Open the 9/16 ø connection to prevent vacuum in the vessel which would hold head in place.
4. Lift and remove top head.
5. Thoroughly clean and dry all separate parts and vessel proper.

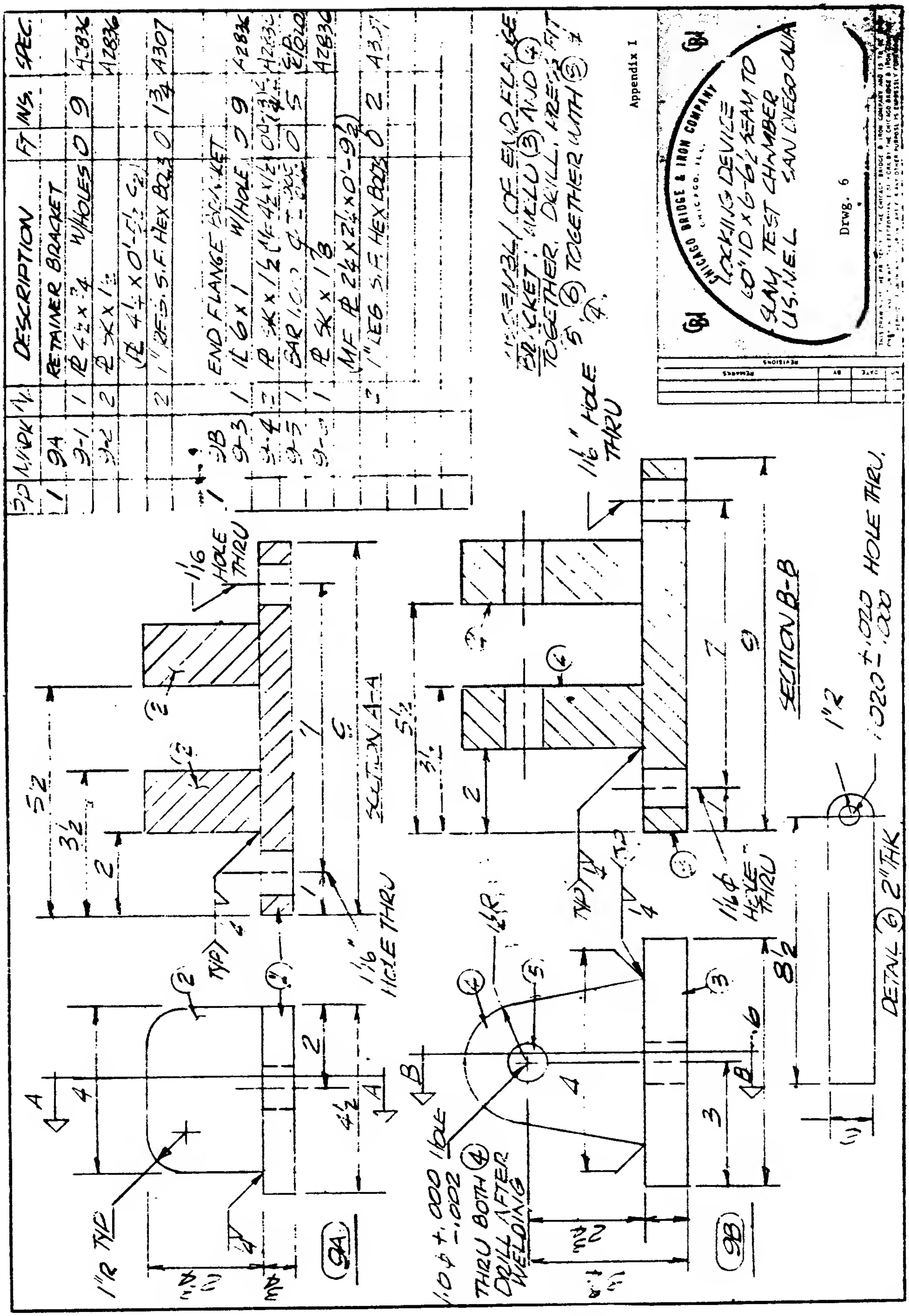

RETAINER RING
APPROX WT: 15,000#
3 EYE-BOLTS &
LOCKING BRACKET
CRANE
SCALE
CLEAN &
LUBRICATE
3 LIFT LUGS
(SHIM PLATES
NYLON BEARING
PADS (6 EA.)
(BOTH FASTENED
WITH 4 - 1/2 Ø SCREWS)
GASKET PROTECTOR, 50#
GASKET HOLDER, 155#
GASKET HOLDER CLIP
(6 EA WITH 1 - 3/4 SCREWS)
TOP COVER
APPROX WT: 10,000#
LOCKING
BRACKET
CLEAN ALL
CONTACT
SURFACES OF
GASKET HOLDER
& GASKET
PROTECTOR RING
LUBRICATE
NOTE: RUBBER
"O" RINGS
ARE ON TOP
& OUTSIDE
SURFACES
OF GASKET
HOLDER.
VESSEL
CLEAN ALL MACHINED
SURFACES TO 6"
BELOW SUPPORT
LEDGE
REV.
NO.
BY
DATE
ENG'G ASSIGNED
CHICAGO
FABRICATOR
CHICAGO
MADE BY - DATE
CHK'D BY DATE
2-25
46
CONTRACT NO.
CHICAGO BRIDGE & IRON COMPANY

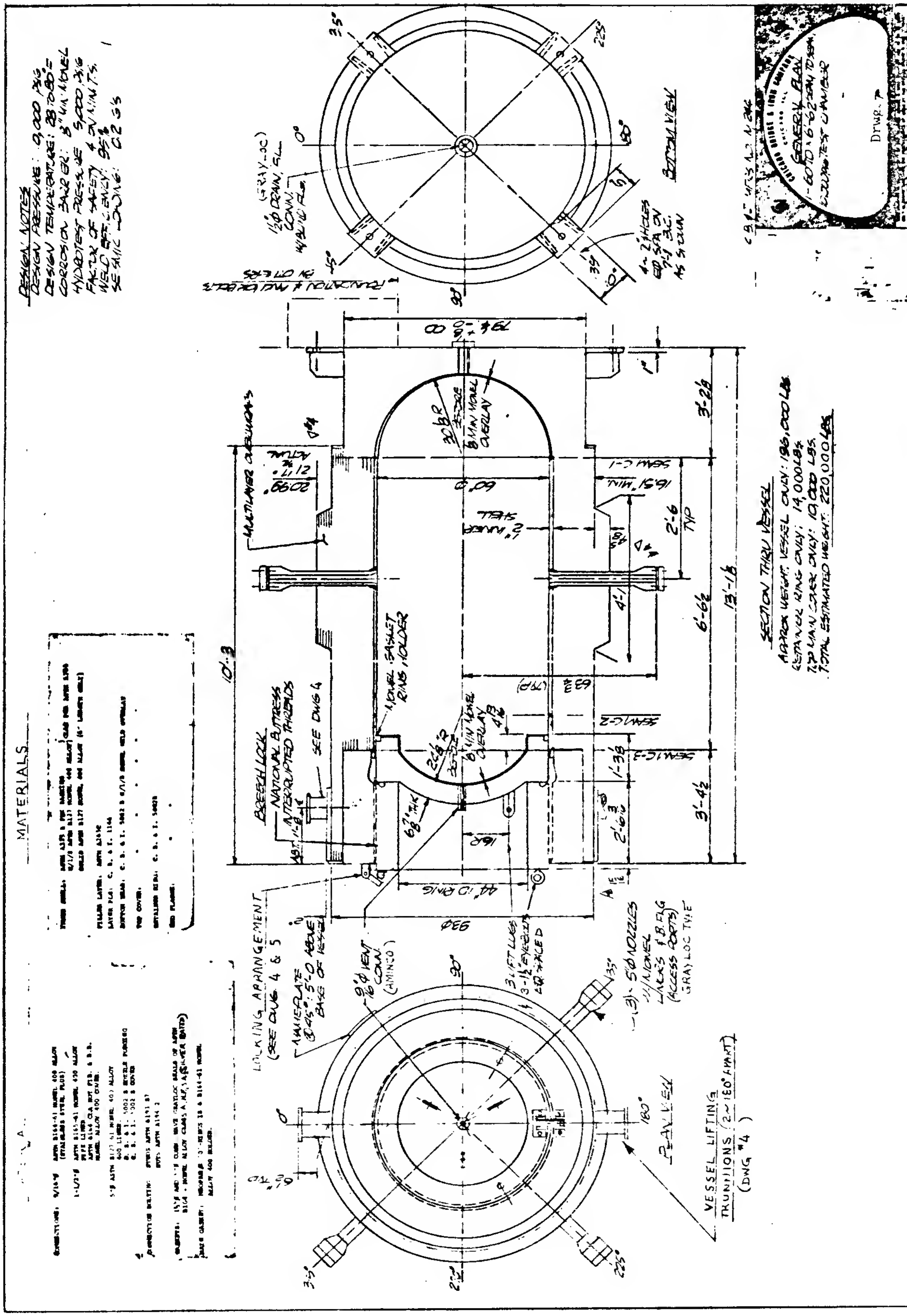

SECTION OF BOTTOM HEAD
DETAIL 'A'
DETAIL 'B'
DETAIL C
1½" DRAIN/FILL CONNECTION
3½" DIA
DETAIL B
NOTE: GRAYLOC CONNECTION, SIZE 1¼ SEAL RING, COVER & STUDS FURNISHED BY GRAYTOOL CO.
BOTTOM HEAD
MACHINING NOTES

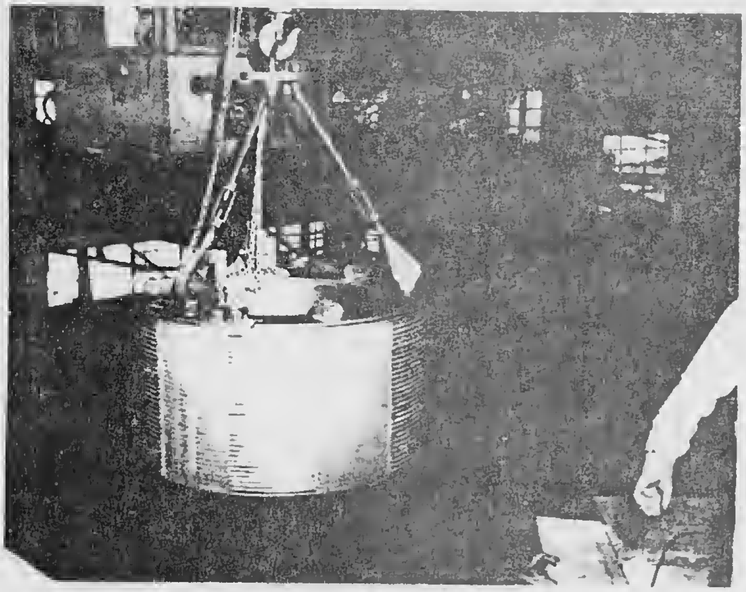

TOP VIEW
TOP COVER
SECTION 'A-A'
SECTION 'B-B'
DETAIL C
WELD DETAIL FOR 3
WELD DETAIL FOR 2
MATERIAL
NOTE:
ALL SURFACES IN GROOVES IN 3 TO HAVE 32 FINISH.
MONEL 400


PARTIAL SECTION OF BREECH LOCK
SHELL END VIEW
DETAIL C
DETAIL-D
ONE THREAD PER INCH
BLEND
DETAILS ABOVE

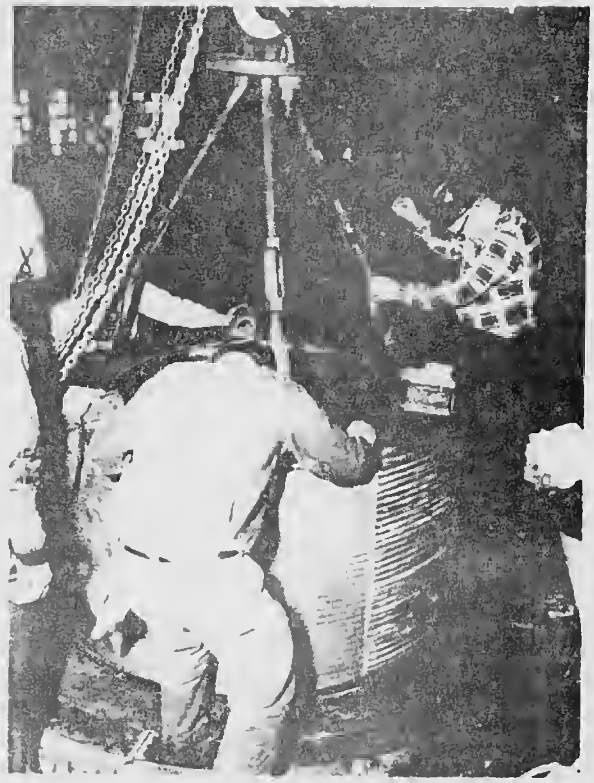

TOP COVER & RETAINER RING ASSEMBLY
NOTE:
AFTER RETAINER RING IS THREADED IN PLACE AGAINST TOP COVER:
1) MATCH MARK RETAINER RING AND END FLANGE. ORIENTATION FOR FINAL ASSEMBLY &
2) DETERMINE PROJECTION OF RETAINER RING ABOVE END FLANGE ELEVATION, L, AND TURN THIS LENGTH TO DIAMETER OF 62.150"
NATIONAL BUTTRESS THREAD (1 THREAD PER INCH)
62.831 MIN PITCH DIA.
62.879 MAX PITCH DIA.
THREAD TO BE A FREE FIT WITH THREADED BREECH LOCK. MACHINE FINISH TO 63 RMS.
ONE THREAD PER INCH
BREAK EDGES
DETAIL-C
6 LONGITUDINAL SLOTS EQUALLY SPACED
THIS SURFACE MUST BE MACHINED TO REMOVE ALL PORTIONS OF THREAD TYP @ EACH SLOT
TOP & BTM LEADING EDGE OF ALL THDS AT THIS LOCATION TO BE CHAMFERED TYP @ 6 SLOTS SEE DETAIL-C
2-1" 8UNC-2B 1¼" DEEP CHAMFER ⅛" DEEP x 30° (BY UNHAMMING VENDOR)
VENDOR NOTE: LOCATE HOLES FOR LOCKING BRACKET AFTER RETAINER RING IS THREADED IN PLACE AGAINST TOP COVER (SEE DWG 4)
3-1½-6NC-2 TAPPED HOLES 3½ DEEP EQ SPA ON 4'-4¾ E.C. BY CB&I (FOR FORGED STEEL EYEBOLTS)
RETAINER RING END VIEW
ARCS ON 63.750 Ø
30°-00': 16.690"
30°-02': 0018"
PARTIAL SECTION OF RETAINER RING
VIEW A-A END OF THREAD
VIEW B-B START OF THREAD
INCOMPLETE THREAD TO THIS POINT TO BE REMOVED. ALL EDGES AT END & START OF THREAD TO BE SMOOTH AND HAVE 1/16" R.
61½" DIA REF
63 FINISH ENTIRE SURFACE BETWEEN THESE DIAMETERS
CHICAGO BRIDGE & IRON COMPANY
RETAINING RING MACHINING
Drwg. 5


Appendix I
CHICAGO BRIDGE & IRON COMPANY
CHICAGO, ILL.
LOCKING DEVICE
60" ID x 6'-6" REAM TO
SLAM TEST CHAMBER
U.S.N.E.L.
SAN DIEGO CALIF.
Drwg. 6
DESCRIPTION
RETAINER BRACKET
END FLANGE BRACKET
SECTION A-A
SECTION B-B
DETAIL 6 2" THK
9A
9B


DESIGN NOTES
MATERIALS
BOTTOM VIEW
SECTION THRU VESSEL
PLAN VIEW
LOCKING ARRANGEMENT
VESSEL LIFTING TRUNNIONS
BREECH LOCK
SEE DWG 4



1

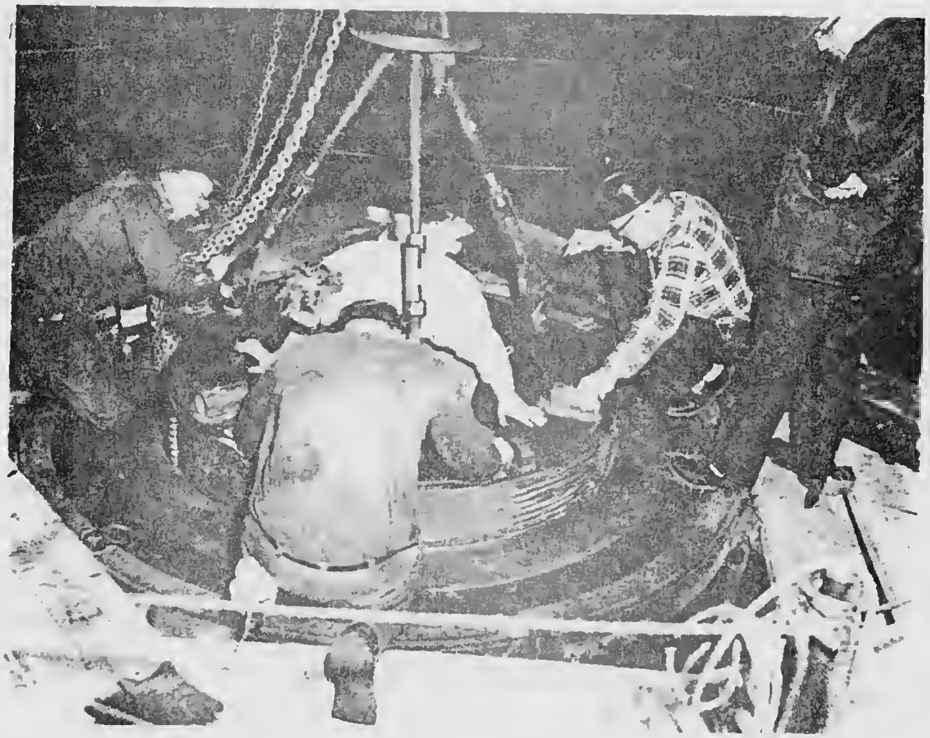


3

Photographs of Top Cover being lowered into place.

4

2



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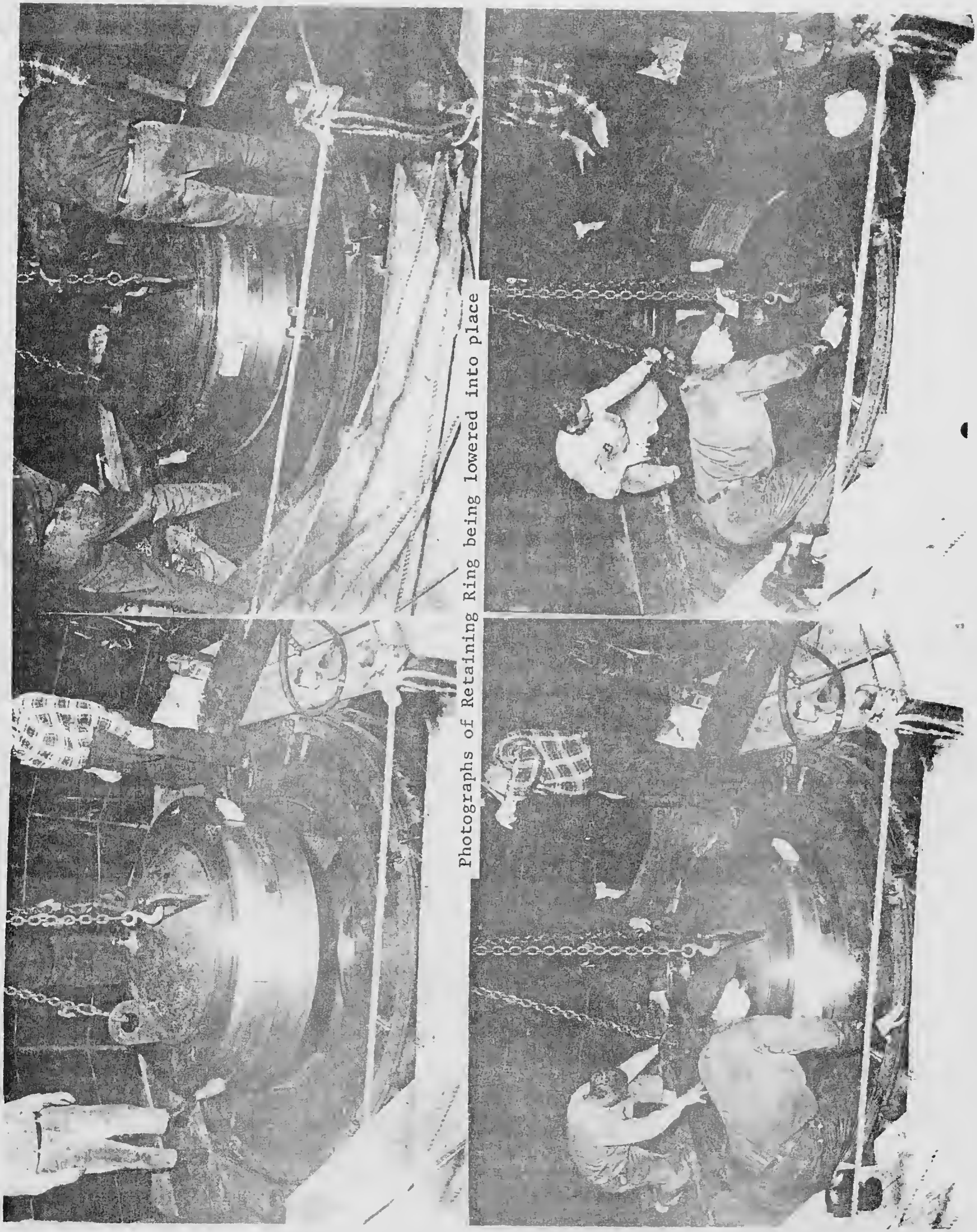
6



Photographs of Retaining Ring being lowered into place

Exhibit C-6

ECL 92C